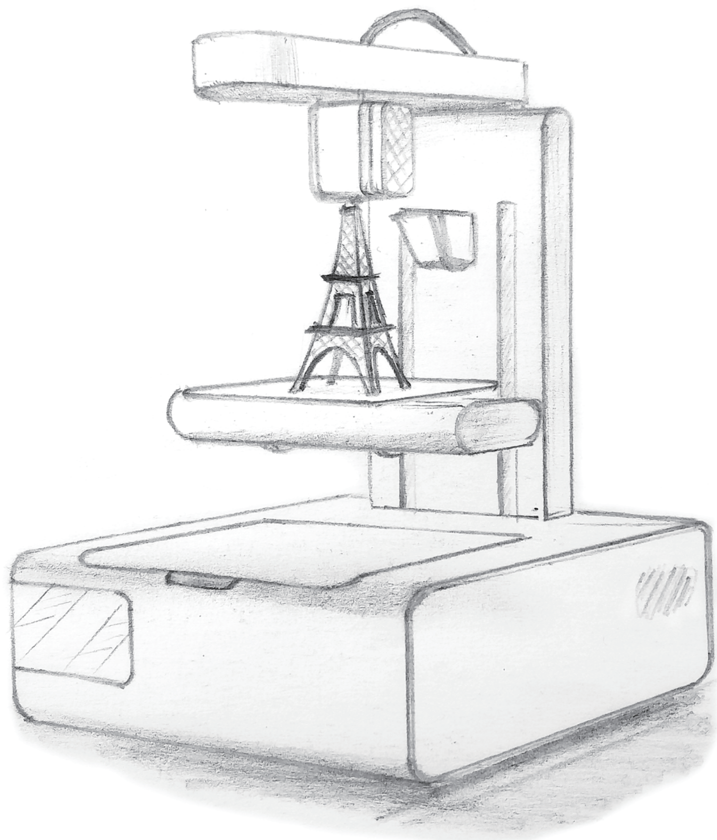
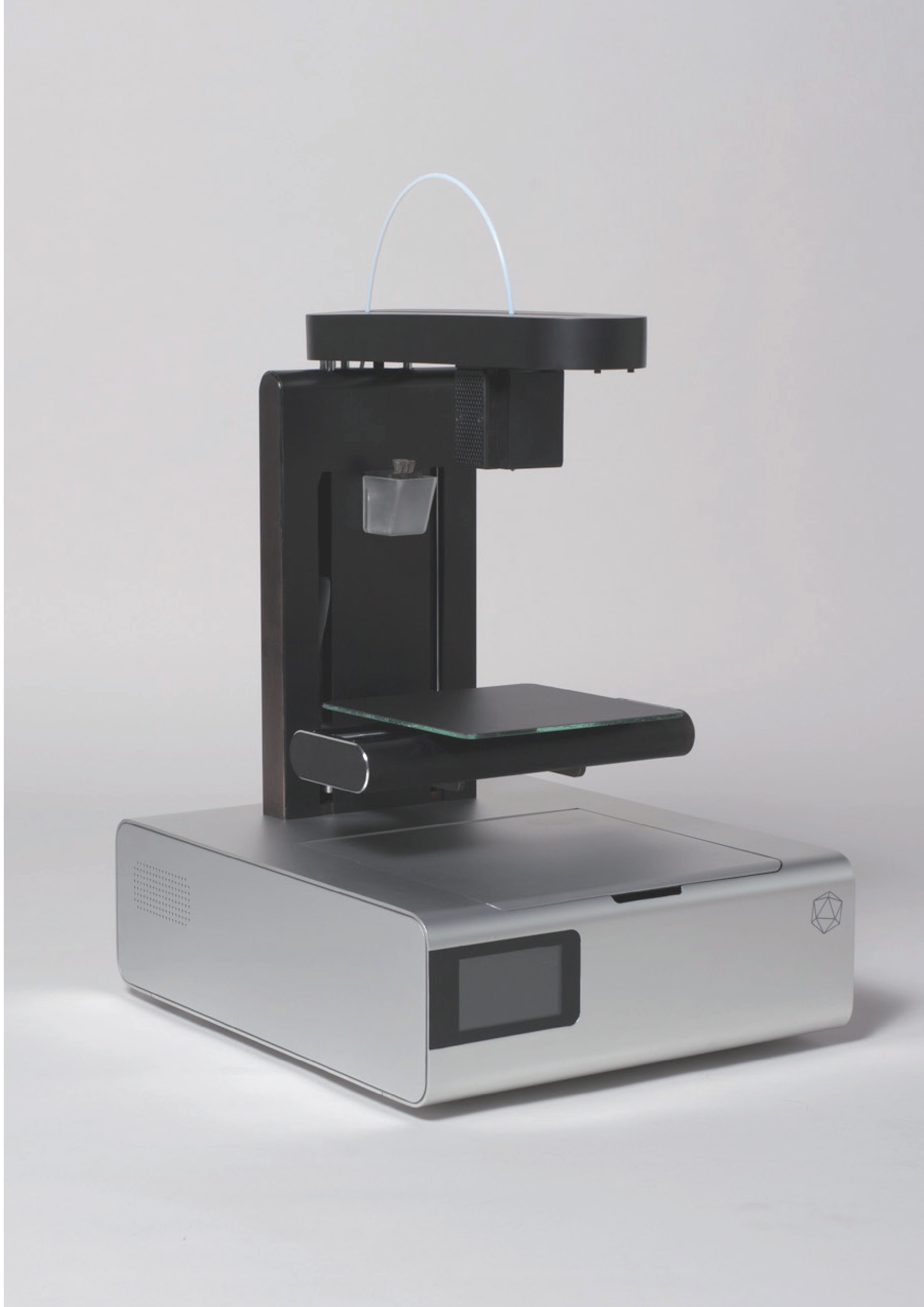


Improving Desktop FDM 3D Printer by User-Centered Design

Huiyang Yu



TITLE / Improving Desktop FDM 3D printer by User-Centered Design

AUTHOR / Huiyang Yu
LEVEL / Master's Thesis
DEPARTMENT / Department of Design
DEGREE / Collaborative and Industrial Design
YEAR OF SUBMISSION / 2019
ADVISOR / Teppo Vienamo
SUPERVISOR / Prof. Eero Miettinen
LAYOUT & ILLUSTRATIONS / Huiyang Yu
PAGES / 122

Aalto University
School of Arts, Design and Architecture

Aalto University
School of Arts, Design
and Architecture

Abstract:

3D printing technology has been receiving more attention in the last decade since it was invented in the 1980s. This trend is especially obvious among desktop FDM 3D printers due to the contribution of the RepRap project. However, there are voices claiming that the undesirable user experience of these desktop machines caused users to believe that 3D printers are just professional toys, instead of a tool. Therefore, it is necessary to understand the needs of users in order to make desktop FDM 3D printers become meaningful equipment. This is the main focus of the thesis.

The main research question of the thesis addresses how User-Centered Design can be used to make the entry-level FDM 3D printer become a useful tool that improves the work efficiency of architects. Besides, the secondary research question is to explore how UCD should be located in the startup business.

In order to fulfill the mentioned tasks, this thesis, on one hand, describes the product development process of the 3D printer project. The project consisted of three phases. The first stage was to define the target consumers and the user requirements, in which I followed UCD methodology, using interview, fieldwork observation and online research to understand their needs and pain points about using 3D printers. The second stage of the project was to come up with solutions and to design the product. I carried out the benchmarking about the existing products and designed the hardware features with my teammates. The last phase was about six-months piloting with five architecture firms in Helsinki. We made 10 prototypes for this pilot and the constant feedback given by clients enabled us to finalize the prototypes. Meanwhile, this pilot also empowered architects to realize that 3D printers are a useful tool that benefits their work.

At the same time, by documenting each stage of the development of the project, the thesis also reflects the mistakes and insufficiencies that happened in this project. At the end of the thesis, the author discusses what would be other possible results of the project if UCD could be applied in a different order.

At the end of the thesis, conclusions are drawn and answers to its research questions are provided. To start with, interacting with users throughout the entire product development process and understanding the requirements of both the general users and the target users are two essential factors that enabled the project to achieve its goal successfully. In addition, it is important that startup companies should place the user research and customer development on the same level. UCD should not be limited by the frame defined by customer development. An inclusive UCD plays a vital role in the success of the startup business.

Keywords: product design, User-Centered Design, 3D printer, additive technology, architecture, startup.

Acknowledgment:

Time flies, while finishing this thesis, my journey of studying at Aalto University is coming to the end. This journey, so far, is the most unforgettable time in my life. From the day I made my decision of applying for Aalto University to the day I landed in Helsinki, from Arabia to Otaniemi, along the way, I am grateful for everyone who helped me.

I would like to express my thank to my thesis advisor Teppo Vienamo. My first knowledge of 3D printing is because of his course, his comments and suggestions helped me to find a way to start and compose my thesis. Similarly, I am grateful for my thesis supervisor Prof. Eero Miettinen. His encouragement and guidance motivated me to complete my thesis.

Many thanks to the Department of Design and every of my teacher during my Master study. I am grateful for Turkka's tough criticize; Simo's "self-explanation"; the supports from Federley Osse and Aila Laakso and every master in the workshop.

My earnest gratitude for every teammate of the project. Thank you Cheng, Jonas, Julio, Martin, Sophia, Sara and Oanh. The one and half year we spend in that small and cozy office will always be my warmest memory. I am also grateful for Kari and Saori from Aalto Design Factory; Solomon and Jason from Aalto Fablab.

Thanks to my best friends in Finland Amar and Mikko, they have been giving me the greatest support in my study, life and this thesis.

Most importantly, my deepest gratitude for my family members, especially for my mother's selfless support. Lastly, I am sincerely grateful for my wife, thank you for having you in my life.

Table of Contents

Chapter 1
Introduction

Technology advancement is significantly changing the way people live and work, this development can be noticed in all disciplines. Among all the industries, product development and production is one of the fields which is experiencing the most dramatic evolution, in which additive manufacturing (AM) technology is playing an essential role [Kearney, 2017]. Over the last decade, AM technology has become an often mentioned term by ordinary people, its advantages such as cost, speed, quality, innovation/transformation, and impact are benefiting our everyday lives(Attaran, 2017).

In fact, "Additive manufacturing, as 3D printing is also known as, is not actually a 'new' technology"(Winnan, 2013, p.12). It was invented by 3D Systems in 1987 by using stereolithography (SL) technology - a thin layer of ultraviolet (UV) light-sensitive liquid polymer is solidified by laser(Wohlers & Gornet, 2014). In addition to the SL system, another type of 3D printing system "fused deposition modeling (FDM)" was commercialized in 1991. It extrudes the thermoplastic material from a hot nozzle and produces the object layer by layer. This approach has become one of the most popular 3D printing methods nowadays due to the RepRap open-source project started in 2005. It aimed to "produce a pure self-replicating device that is not for its own sake, but rather to assist individuals by a low-cost desktop manufacturing system that would enable the users to produce the artefacts which are used in everyday life"(Jone et al, 2011). Since then, 3D printer technology has become more affordable and accessible for ordinary people and the general public. However, as 3D printers have been increasingly used, these low-cost desktop machines were also being criticized due to the unfavorable usability and user experience.

During the second course of my Master study at Aalto University, I had my first opportunity to use a 3D printer to print my design project. Since then, 3D print technology has become an indispensable part of my design career. Then, I was fortunate enough to participate in a project that was initiated by a startup company to develop a 3D printer. The goal of the project was to develop a user-friendly 3D printer. In this project, I was not only in charge of the Industrial Design, but also I had the opportunity to take more responsibility. This experience empowered me to have a more profound understanding of using User-Centered Design to develope product. Meanwhile, this startup journey motivated me to introspect my design process.

Hence, One of the purposes of this thesis is to state the development process of this project. It will discuss how User-Centered Design can be utilized in each stage of product design and development, empowering 3D printers to be a useful tool that can enhance the users' everyday working efficiency. In addition, along with describing the development process, the drawbacks and mistakes happened in this project will also be revealed. Therefore, the other core idea of the thesis is to reflect these mistakes. By doing that, this thesis will try to provide a clearer way for readers, helping them avoid repeating the same mistakes.

1.1 About the project

The project was about a consumer-level FDM 3D printer design and development process in a startup company called Plationics Oy. The team consisted of a small group of people from different backgrounds. The project started in July of 2016 and ended in January of 2018. The one and half years of product design and development process can be generally divided into three stages, but there was not a clear boundary for each stage as the situation and environment in a start-up company change extremely fast.

The first stage was mainly about customer development and user research, in which the potential market was firstly defined, and according to the target market, the user study was carried out in order to understand the user requirements. Followed by the product design and development stage that the relevant solutions were generated and applied to the product in order to solve the problems and satisfy the user requirements found from the user study. Then, several prototypes were made in the next stage in order to continue the product evaluation which was the third stage of the project.

The goal of the project was to design a fully automated consumer-level FDM 3D printer that can be used for architects to benefit their daily works. Therefore, Several methodologies were used during each development stage to better understand the needs of users and the potential market and to provide guidance for the product development process in the startup context, including the user interviews which followed the user-centered design approach and lean start-up methodology. These approaches also helped the product to find out its key differentiators in the highly

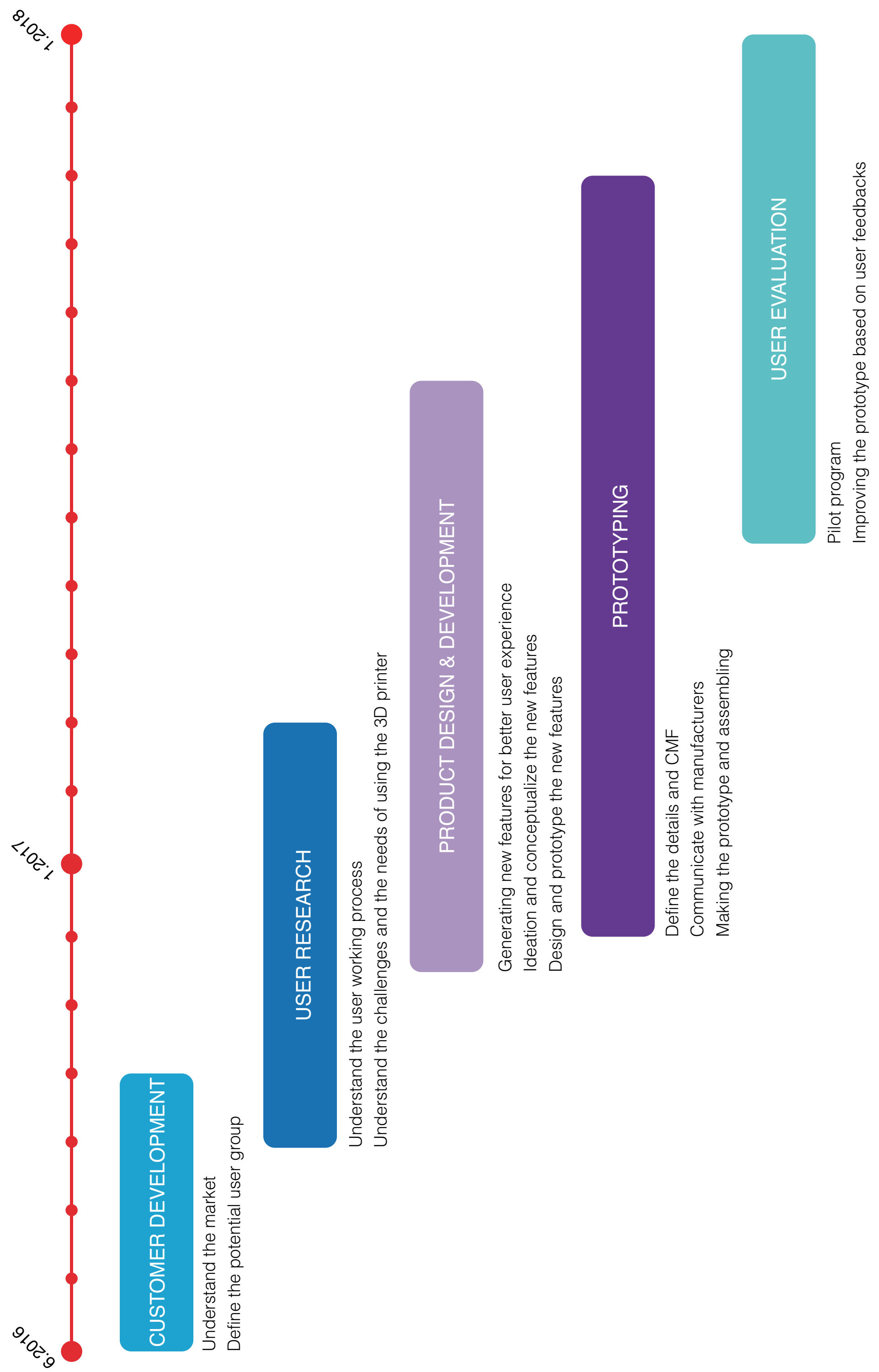


Figure 1 shows the stages of the project

competitive 3D printer market.

The product ended up with not only the user-friendly hardware but also a unique software which was inspired by the targeting user. New hardware features included auto-bed leveling and swappable nozzle. New software feature was an auto-STL file converting application. These new design features provided users with better user experience and usability. Unfortunately, the project ended with a shortage of funding so that it failed to move to production.

This thesis will mainly focus on the hardware development part because I was mainly in charge of the hardware design part.

1.1.1 The motivation of developing the 3D printer

Even though there have been voices claiming that 3D printing technology could trigger a new industrial revolution, over 30 years of development, this technology is still not yet as commonly used as other types of manufacturing methods until the emergence of low-cost, desktop FDM 3D printers revived the public attention (Zhang & Jung, 2018). Nevertheless, these low-cost FDM 3D printers could not always guarantee the printing quality. This brings the negative user experience and makes users misunderstand that, perhaps, 3D printer is just a playful toy, but is not truly reliable as a tool instead. This issue was one of the triggers which motivated the birth of the project. The team believed that at that time, there were many improvements could be done to develop a 3D printer to provide users with a better user experience and to make the 3D printer become a useful tool.

In addition to the technic point of view, the 3D printer industry has been witnessing a booming since 2014. The market demand has been dramatically increased due to the significant drop in the cost and the increasing accessibility. Wohlers Report 2018 has predicted that the 3D printer market would continuously grow in the coming future (McCue, 2018), plus the healthy start-up environment in Finland gives solid supports to newly built business. Therefore, the market needs and the convincing future of AM technology encouraged the start of the project.

1.1.2 The role I played in this project

This project was funded partially by Business Finland, partially supported by the three owners who were specialized in Electronic engineer and Marketing. I joined this project at the very beginning stage and started participating in the product development process, mainly involving the user research, benchmarking, concept design, prototyping, product evaluation and design for manufacturing.

The user research and customer development were conducted by the entire team. During this stage, interviews about the potential users were carried out by the whole team. Fieldwork observations and user experience workshop were employed with the support of two designers (one Industrial designer, one UX designer). Meanwhile, five architecture firms in Helsinki also made remarkable contributions to the project, there was a pilot collaborating with these five architecture firms, and feedback gained from the pilot gradually made the product to be ready for production.

It is difficult to draw a clear line to divide each individual's responsibility in a startup due to the limited resources in terms of the funding, time and human labor. However, there were certain tasks that were completed by myself individually and those especially happened in the second stage. To be specific, the industrial design, prototyping and auto-bed leveling conception were my individual work, however, the further development processes could not be possible without the support from the rest of the team.

1.1.3 Multi design methodologies in this project

Given that the project was about developing a product in a startup environment, thereby, the methodologies in this project were not merely followed the approaches that used in the design research area, but those could benefit the strategic level also played an important role. However, defining the user requirement had always been the center of the research process. So, User-Centered Design was applied to guide the product design and development process. In addition to that, customer development and product development also followed the Lean Startup Methodology.

In the first stage, the semi-structured interview was the most essential research approaches. It provided guidance for the team to find out where the idea could be located in the market. In addition, due to the data collection nature and the analytical nature of the interview (Rohrer, 2014), the answers obtained from interviewees enabled the team to understand the core requirements in terms of both users and the market, thereby, ensuring the product to meet the user requirements.

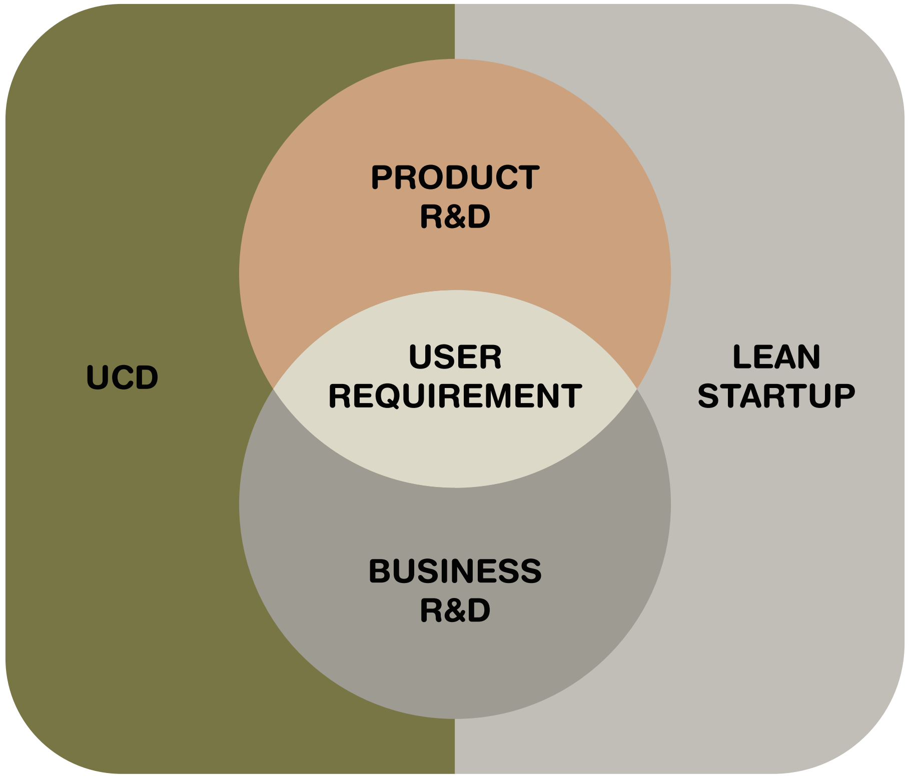


Figure 2 shows the methodologies used in this project

Fieldwork studies and user experience workshop were also carried out in order to further understand the challenges that users might face during the actual using 3D printers. One Industrial designer and one UX designer were invited for the workshop; the data sorting of the workshop was supported by them as well.

The product evaluation stage also followed the UCD approach, in which frequent user interviews by different forms were implemented in order to improve the product based on the user's suggestion. Besides, Co-Design with users was also utilized.

1.2 Thesis objectives and Research questions

The objective of the thesis is to discuss and analyze how User-Centered Design can be used in product development in a startup context to generate new solutions which improve the product user experience. To be specific, The thesis will describe that in a 3D printer development project, the potential user group was defined by following the Lean Startup methodology. Then, by using the UCD approaches, the development team was able to understand the user requirements and to find the pain point of using 3D printers, therefore, corresponding solutions could be generated which added the extra values to the product so that the product eventually could be able to improve the working efficiency of architects.

In addition to that, there were mistakes happened during the product development process. Therefore, other than explaining project progress, personally, it is necessary to reflect the mistakes so that this thesis could bring values to those who will start their startup lives, helping them have an idea about how to balance the role that UCD should play.

Research question: *In the startup context, how User-Centered Design can be used to make the entry-level FDM 3D printer become a useful tool to improve the working efficiency of Architect?*

Secondary question: *How UCD should be located in startup business?*

1.3 Thesis structure

Chapter 2: This chapter will explain the definition of the design methodologies that had been used in the project. There will also be an introduction about the working principle of FDM 3D printer, thereby, letting the readers understand the key elements of the machine and the relevant terminologies mentioned in this thesis.

Chapter 3 will describe how the customer development process was carried out and the reason for entering the architect market. In addition, the user research was conducted and by doing that, the customer requirements, expectations and challenges about using 3D printers were defined. Furthermore, there will be a short reflection about this stage and a discussion about other possibilities could be done which might lead to different results.

Chapter 4: This chapter is the documentation about the product development process, in which, swappable nozzle and auto bed leveling were developed and prototyped. Besides, there will be a reflection about the development procedures of the swappable nozzle which motivated me to rethink the key factors of the product development process in the startup context.

Chapter 5 is about the user evaluation of the project that a pilot program collaborated with five architecture firms was carried out. The pilot program further finalized the project, making it ready for massive production.

Chapter 6: The discussion and conclusion of the thesis will be presented in this chapter.

Chapter 2

Theoretical Terminology & Methodological Framework

2.1 Theoretical Terminology & basic working principle of FDM 3D printer

Fused Deposition Modelling (FDM) 3D printer is one of the most common additive technologies that people are using nowadays. Its benefits such as clean, easy to use and environmentally friendly make it highly popularized among all kinds of users (Stratasys, n.d.). Actually, only basic components such as an extruder, a hot-end, a nozzle, a build plate, the filament, and the X, Y and Z axes mechanisms can already construct the simplest FDM 3D printer.

Marcincinova and Kuric defined the working process of an FDM 3d printer as “a plastic or wax material is extruded through a nozzle that traces the part's cross sectional geometry layer by layer. The build material is usually supplied in filament form. The nozzle contains resistive heaters that keep the plastic at a temperature just above its melting point so that it flows easily through the nozzle and forms the layer. The plastic hardens immediately after flowing from the nozzle and bonds to the layer below. Once a layer is built, the platform lowers, and the extrusion nozzle deposits another layer.(2012, P.24)”.

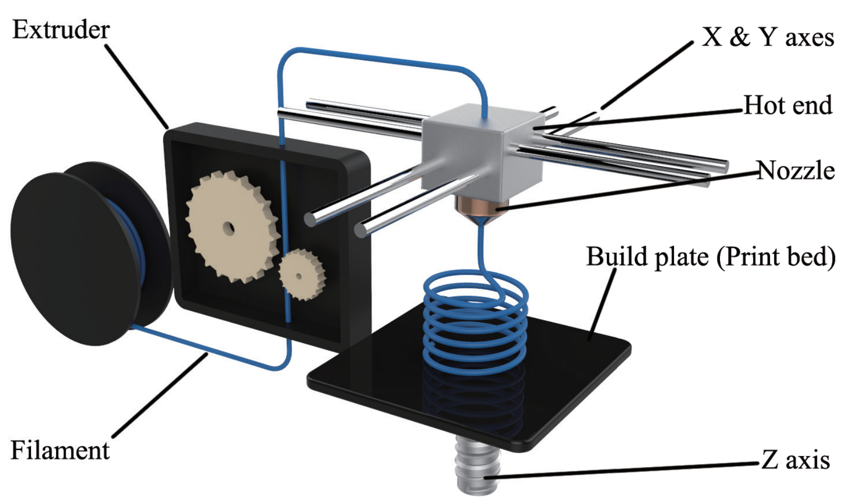


Figure 3 shows the basic parts of an FDM 3D printer

The extruder: According to the definition provided by Sculpteo(n.d.), the extruder on an FDM printer is the part that extrudes the plastic filament in a liquid form and deposits it on a printing platform by adding successive layers. Extruders can be categorized into direct and Bowden extruder. A direct extruder is directly attached to the hot end, it is integrated to the printing head, while a Bowden extruder is also called remote extruder which remotely connects to the hot end by a Teflon tube. Both kinds of extruders work rely on the gear rotates driven by a stepper motor which pushes the filament to the hot end. The extruder used in this project was a remote extruder.

The filament: FDM 3D printers use a special type of thermoplastic which will become flexible once it reaches a certain temperature as the printing material. Currently, one of the most used filaments is made of PLA (Polylactic acid) - A biodegradable material extracted from materials such as potatoes and corns(Raquez, Habibi, Murariu, Dubois, 2013). Another main filament is made of ABS. In this project, PLA was chosen to be the printing material because of its environmentally friendly property.

The hot end: The hot end is responsible for heating the filament up to its melting point which enables the filament to be liquified and to be extruded to form the designed objects. Hot end and the nozzle are the most important parts for the printer head.

The nozzle: The nozzle is the component on a 3D printer which deposits the molten filament onto the built plate(MatterHackers, n.d.). Most of the nozzles are made of brass, while there are nozzles made of stainless steel as well. The common size of the nozzle is ranging from 0.2mm to 0.6mm. The bigger the number is, the rougher the print outs will be.

The build plate: The build plate or so-called printer bed of the 3D printer is a flat surface on which the molten filament will stick to and solidify. The surface materials and roughness of the build plate influence the print outcomes significantly. This project eventually utilized Geckotek build plate.

The X, Y and Z axes mechanisms: The X, Y and Z axes mechanisms provide the 3D printer with the moving functions, in other words, they enable the printer head and build plate to move to the computed locations, therefore, ensures the object to be formed.

2.2 Design methodologies

The design process in this project followed the User-Centered Design approach, in which different interviews were carried out along with the workshop and fieldwork studies. In addition, the entire project was developed under the startup context, therefore, this project took lean startup methodology as the guidance.

2.2.1 User-Centered Design (UCD)

Don Norman in his book "The Design of Everyday Things"(2013) defined User-Centered Design as an approach which places human requirements, capabilities, and actions in the first place, using design as a way to address the mentioned requirements. Sanders (2002, p.1) stated that "In the user-centered design process, we are focused on the thing being designed (e.g., the object, communication, space, interface, service, etc.), looking for ways to ensure that it meets the needs of the user". IDEO also defined UCD as a process that consists of three phases, starting from understanding the users' needs and ending with delivering the tailor-made solutions to satisfy their needs (IDEO Design Kit, 2015). Based on the well-rounded definition of UCD, it is obvious that the core of User-Centered Design is not only about human or user, more importantly, the need of the user is the top priority.

However, people's needs differ case by case. Therefore, it is important for designers to consider the needs of users within a context in order to fully understand what they want. This is also emphasised by Don Norman in his article "Human-Centered Design Considered Harmful"(2005). In fact, once we consider users and their requirements within a certain context, the term "user" can interestingly become a verb instead of a noun in the English grammar. In other words, "user" in a context is not static or passive, rather it is an active element, that uses and evaluates products and the accompanying experience. When designers start to conceptualize a new football, for example, the center of the design is not to render the football soft and comfortable for the athletes to kick it. On the contrary, the main task of the design might be to bring some changes or challenges into the track of the football's velocity, to make the ball's speed faster to bring more difficulty to players and goalkeepers to catch it. In this case, it seems that the football design completely opposes the view of UCD. Yet, if we consider the football activity as the context, then the aim of the design is to improve the entire game. Indeed, People play football for fun, excitement or competition instead of for relaxation and comfort.

Thus, UCD was applied in this project to understand the need of architects and to explore the possibilities that using 3D printers to assist their daily work so that to improve their working efficiency.

2.2.2 Interview

Given that one of the core tasks of UCD is to understand the needs of users. A series of methods that help designers and design researchers read the user's thoughts have been, thereby, applied in UCD methodology. Among them, the interview is one of the most common and effective methods, especially in the early stages of design exploration.

According to IDEO (IDEO Design Kit, 2015), "Interviews really are the crux of the Inspiration phase, Human-centered design is about getting to the people you're designing for and hearing from them in their own words." Given that the core of UCD is to understand the requirements of users, letting them speak is an efficient way to investigate the users. Furthermore, Bogner, Littig & Menz mentioned that "talking to experts in the exploratory phase of a project is a more efficient and concentrated method of gathering data than, for instance, participatory observation or systematic quantitative surveys(2009, p.2)". They highlighted that conducting expert interviews is a time-saving information collecting approach because experts are considered as the crystallization of knowledge and practice.

In addition, as UCD is gradually becoming more inclusive, the design perspective also has shifted from only focusing on understanding the basic issues that users expressed to further investigating and visualizing their subconscious needs. According to Keinonen(2010), "User-centered design includes both harm protecting orientations and those where the priority is in creating new kinds of value. The development trend from the 1980s to 2000s has been towards catering for a wider range of goals rather than just advancements on the protection dimension". Among these goals, user experience is one of the emerging values that has gained its own importance in the UCD. Sanders (2002) pointed out that through interview and observation, designers and researchers can have access to people's experiences and then transferring the user experiences into inspiration and ideation for design.

However, there are factors that need to be taken into careful consideration when carrying out the interview. Undeniably, listening to a story told by the user can be inspiring, it can be helpful for designers and researchers to understand the pain point or the desire of the user. Nevertheless, it is necessary to highlight that answers provided by interviewees can sometimes be interruptive because what they said might not be the same as what they really do(Stiftung, n.d.). Therefore, the semi-structured interview is developed and it has become one of the most used methods to collecting qualitative data as it enables the interviewees to share meaningful information in a relaxing atmosphere on one hand, on the other hand, interviewers can manage the interview process in order to guarantee the quality.

In this project, semi-structured interviews with a wide range of users were initially conducted. Afterwards, the expert interview was applied for further exploration.

2.2.3 Lean Startup Methodology

The notion of Lean thinking or Lean Startup Methodology has been widely accepted and adopted in recent decades, this is especially obvious in the startup environment or enterprises creating new products. Eric Ries(2011) mentioned that the idea of Lean Startup Methodology originated from the lean manufacturing revolution. It was developed by Taiichi Ohno and Shigeo Shigo at Toyota. It emphasizes radical lean thinking which detects and eliminates any extra waste of sources and focuses on the most essential factors which can accelerate the development of the business and the product.

Lean thinking breaks the conventional way of the product development process, it effectively develops the business in terms of both the cost and the time aspects. One of the key points in this idea is to communicate with the users or the customers time to time throughout the development process, making each stage flexible enough so that the constant user feedback can direct the product development and the business strategy. This prevents the startup from blindly designing something that no one wants to buy. According to Erin Griffith (2014), lack of consumer interest is one of the most essential factors causing the failure of startup companies.

Eric Ries(2011) defines the startup as “a human institution designed to deliver a new product or service under conditions of extreme uncertainty”. Despite 3D printer is not something new anymore, back to the year 2016, there were few consumer-level 3D printers targeting Architecture industry, and architects had not yet utilized AM technology during their working process very often. This means that the project was still facing many uncertainties. Therefore, the idea of the project was to borrow the Lean Thinking in both the business development and the product development so as to quickly exam our hypotheses and safeguarded the strategy of the project.

On the other hand, it is noticeable that Lean Thinking and User-Centered Design share many similarities. For example, Lean thinking highlights the importance of learning from the customers and being flexible for adjusting the strategy, it focuses on what the customers really want to have instead of guessing what they might want. Similarly, UCD always emphasizes the user requirement during the product development process. However, UCD is concentrating on the product development aspect, while the Lean Method is more about in a business and management context, it stays on the strategic level. But since Lean Thinking also originated from product development, not to mention that in the actual situation, product development, marketing and business operation are interdependent. Therefore, the ultimate purposes of Lean Thinking and UCD are very close.

Chapter 3

Customer Development & User Research

There has been a significant increase in the consumption of AM technology since 2010, while this technology in 2016 was still not that mature. It means that there was indeed a huge market. However, it was still important to find the niche market because, for one, there had been already a huge competition in the market due to the limitation of the usage of AM technology and the significant drop of the cost, this means without a unique selling point, there was no necessity to reinvent the wheel. For another, this project was started by a small group of people with limited time and budget. Therefore, it was important to balance the customer requirements and the capacities of the small team. Undeniably, developing the desired features was important, but it was even more crucial to wisely pick up those most valuable points that we were capable of doing to develop. Hence, Customer Development and User Research were the initial steps of the entire project.

3.1 Customer Development

The customer development used qualitative research, it was the first stage which was about exploring a wide range of possible markets that the project could fit in. Then, the potential customer was chosen by filtering and analyzing the data got from the first stage research.

3.1.1 Defining potential market

3D printer may benefit different industries as long as they have the requirements for making tangible products. However, each sector has its unique expectation or desire towards AM technology. For example, a jewelry designer may value the surface finishing of the prototype outweighs the strength of the material, while mechanical engineers tend to focus on the precision of the printed objects. These hypotheses have to be examined by asking real customers (Blank & Dorf, 2012). Therefore, doing customer discovery was the first step of the project because according to Black and Dorf (2012), many startups failed because of their inappropriate understanding of their customers.

Hence, interviews with about 40 customers from different industries were conducted at the beginning of the project. The goal of these interviews was to obtain a wide range of data so that they could be filtered and analyzed in order to help the project find out its most appropriate position in the market.

The objects of the Initial Interview:

Understand how much does every industry know AM technology.

Understand the value that AM technology can bring to each industry.

Understand the expectations of each industry for AM technology.

Understand the challenges that each industry was facing with AM technology.

Interviewees:

Industrial designers, educational institutes, jewelry designers, engineers, architects and amateurs were the main professions selected as interviewees. Each group contained interviewees with different levels from all over the world, which means individuals, firms, students were all involved in.

Methods:

Phone calling interview with an email invitation: The interview was carried out by phone call conversation. In most cases, an email was sent before calling the interviewee in order to agree with the schedule. The conversation started with a polite greeting and introduction. Followed by asking questions from a prepared questionnaire (appendix) and note-taking.

Compared to the face to face interview, phone call interview, as a way of conducting qualitative research, has received many biases (Novick, 2008). However, the phone call interview is a time-saving and cost-efficient method to quickly collect a wide range of data, this is especially true in terms of the quantitative data collection (Novick, 2008; Chapple, 1999; Sturges & Hanrahan, 2004; Sweet, 2002; Tausig & Freeman, 1988) because researches do not have to spend time traveling and arranging the agreed time with interviewees. This method is also suitable for a startup who does not own many resources. Actually, we noticed from doing these interviews that firms or individuals post their contact information on the website usually means they are open to collaboration. Even though rejection happened from time to time, it was normal phenomena in conducting interviews.

However, it is worth to mention that this method has drawbacks as well. For example, interviewees might not value phone call as official as the face to face interview, so, they might provide random answers. Besides, the phone call interview in certain cases is not suitable for conducting in-depth research, for example, visual cues and time limitations can often restrict the phone call interview(Novick, 2008; Garbett & McCormack, 2001).

Nevertheless, this step was meant to gain the customers' insights on a general level, therefore, the phone call interview was chosen as the method.

Questionnaire: A series of questions were prepared in order to guide the interview. Also, it is possible that the phone call was not conducted in a suitable time, while the questionnaire enabled interviewees to answer the questions later.

Results:

From the interviews and the responses of the questionnaire, it was obvious that each industry had its own requirements, while there were some common features or expectations shared by them as well. In addition to the user requirements, there was an interesting found which was that the level of familiarization with AM technology varies a lot from different industries.

Profession	Interviewee	Find out
Engineer	There were 12 engineers from Finland, China and Sweden participated in the interview, including individual freelancers, lead engineers in big companies and owner of engineer service agencies.	The requirements were different from each interviewee, however, there were common needs. Firstly, they needed an accurate machine. Secondly, the printing size was crucial. Thirdly, there were nine interviewees who had specific material requirements, while three of them mentioned that they preferred 3D printers can print metal material. Engineers also gave the information that CNC was a more reliable way at that time due to a wider range of material options and the manufacturing speed. In addition, they indeed admitted that 3D printer has the advantages of prototyping complex shapes; however, for them, AM technology, especially the desktop machines were more like a toy which could not satisfy their functional testing purposes.
Designer	There were 2 industrial designers, 2 Jewelry designers, 3 design students, 3 freelancer designers and 6 design agencies from Finland, China, Sweden, Japan and India accepted the interview.	Almost all the designers had experiences with using 3D printers and they claimed that they value the finishing of the printout. Jewelry designers had a huge fascination towards Formlab due to its translucent material and its nice finishing. In addition, Designers believed 3D printer would be largely used in the future, but, at that time, the pre and post-processing were the main issues which stopped them from using 3D printers.

Educational institute	5 educational representatives were involved in the interview from Finland and China.	In educational institutes, a wide range of 3D printers were needed because students' demands were different. However, they valued the reliability more than any other factors because of the deadline of student projects and the large demands from students.
Architect	8 interviewees related to architect field such as architecture students and senior architects participated in the interview.	It was surprising that many of them had never used a 3D printer even though they all more or less heard this technology. Despite this, they had the requirements and anticipations about AM technology. For those who previously had experience with the 3D printer, they valued the reliability as architects' hourly salary is relatively high, the architecture firms wanted the 3D printer to help them to save time and cost instead of letting their architects spend several hours repairing the machine. In addition, They said 3D printers can help them to make the prototype which cannot be made by CNC. For those who lacked experiences with the 3D printer, they tended to believe that 3D printer can do magic works, but there was negative news about AM technology such as unfavorable user experiences and outcomes which blocked them to try this technology. However, in general, they were curiosity about 3D printers and would like to try.
Others	2 3D printer amateurs and 2 3D print service providers also participated in the interview.	3D print service providers evaluated the 3D printer in a stricter way compared with other professions because, for them, a 3D printer is a tool to maximize their profit. Therefore, they preferred commercial-level products instead of consumer-level machines. In contrast, amateurs preferred the open-source 3D printers because they give them the flexibility to play with. Meanwhile, they were price sensitive.

3.1.2 Data grouping and Analyzation

After collecting the data from all the industries, we started analyzing the information and figuring out the direction of the project in accordance with the capabilities of the team. As a startup, we understood that the team had limited capacities, which means there were some features we could do, while there were some which were out of our ability. For example, it is obvious that a metal 3D printer with all the possible automation systems can meet almost every user's requirement, but it is impossible to be achieved within a short period of time for a start-up consists of four team members from different disciplines. As Eric Ries emphasized in his book "The Lean Startup" (2011), the startup has to quickly and wisely find out the customers' desire.

Fgure 4 is an illustration of the outcomes balancing our own capacity and the user requirements. The analyzation process was similar to a filter, it narrowed down the options, and thereby, found out the direction.

Among all the groups, architects had the least experiences about AM technology. This could either means that the market had not yet been filled, or AM technology was not needed there. Considering architects' work and the data generated from the interviews, AM technology indeed was useful in their daily work, just this market was still empty. This means there could be a huge potential waiting to be explored, at the same time, this empty market also indicated that there would be more uncertainty. Given that startup is meant for developing things under the uncertainty, the team, therefore, chose to step into the architect industry.

In addition to the filtering process, two of the team members also researched

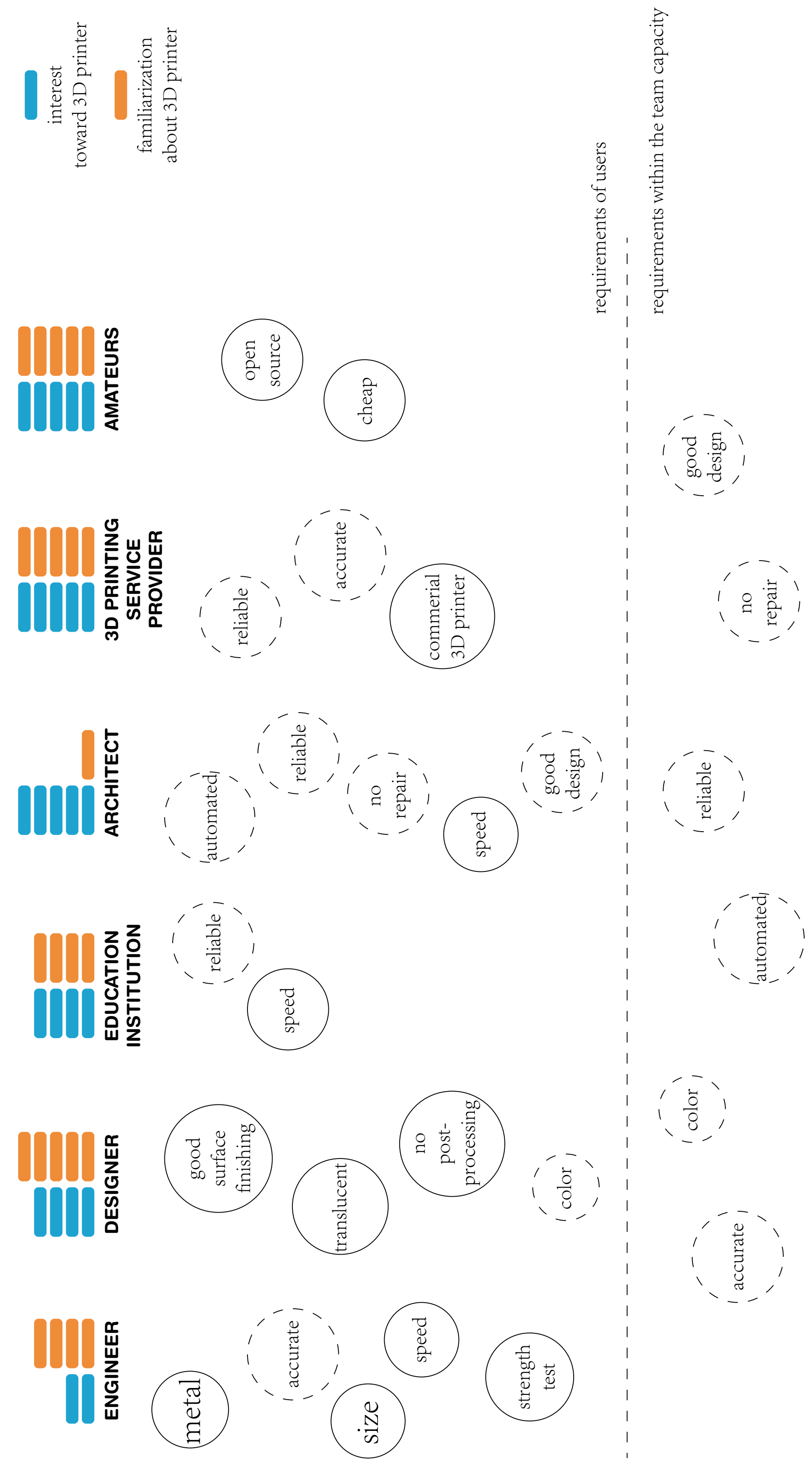


Figure 4 shows the filtering process of customer discovery

the Architect market. According to the data provided by Architects' Council of Europe (ACE | 2016), there were 158,342 architect firms in Europe in 2016 and each firm consisted of 4 architects on average. The market value behind this huge data was about 17 billion euros and it was steadily growing each year. On the other hand, the worldwide shipments of 3D printers were also experiencing a dramatic increase, rising from 108K units in 2014 to 496K units in 2016, this figure was predicted to be about 5.6M units in 2019. These statistics encouraged the team to believe that targeting architects would be a good decision.

ESTIMATED NUMBER AND SIZE OF ARCHITECTURAL PRACTICES

number (estimate)	size of architectural practice (number of architectural staff)							TOTAL
	1 staff	2 staff	3 to 5 staff	6 to 10 staff	11 to 30 staff	31 to 50 staff	over 50 staff	
Austria	1 076	394	265	79	16	1	0	1 832
Belgium	2 357	499	379	81	27	6	1	3 350
Bulgaria	424	157	232	30	10	2	0	856
Croatia	300	177	172	28	16	1	0	695
Cyprus *	180	36	59	17	2	0	0	295
Czech Republic *	857	776	187	70	22	0	0	1 912
Denmark	1 002	132	125	83	64	7	8	1 422
Estonia *	100	57	74	14	2	0	0	246
Finland	289	81	77	49	25	5	2	528
France	5 897	884	692	181	93	5	1	7 753
Germany	31 378	5 105	3 099	762	206	8	1	40 558
Hungary *	987	194	139	27	9	1	0	1 356
Ireland	450	158	100	24	19	2	1	754
Italy	47 009	4 957	3 192	445	106	7	3	55 720
Lithuania	190	68	50	23	6	0	0	337
Luxembourg	91	34	30	20	14	1	0	190
Malta *	45	15	25	8	6	1	0	99
Netherlands	1 980	961	568	130	38	7	9	3 692
Poland	2 790	503	527	245	59	12	4	4 138
Portugal	1 647	647	887	202	76	16	5	3 479
Romania *	683	293	423	237	24	5	1	1 666
Slovakia	250	114	65	17	4	0	0	449
Slovenia	198	117	107	17	3	1	0	444
Spain	5 651	1 159	1 034	184	34	11	5	8 077
Sweden	709	153	130	57	49	8	8	1 114
Turkey	3 450	2 772	2 937	815	312	32	22	10 341
United Kingdom	4 257	878	1 134	398	273	63	35	7 037
2016 EUR-27	114 247	21 319	16 706	4 243	1 516	202	108	158 342
per cent of practices	72	13	11	3	1	<1	<1	100

Figure 5: Number and size of architecture firms in the EU

Source: www.ace-cae.eu

3.1.3 In-depth Research - The further discussion with the potential customers + Understand how architects can obtain benefits by using 3D printers

The first stage of customer development was a quantitative study of the overall market. From a top view perspective, it defined architects as the potential customer. Afterwards, The team conducted a series of further interviews with 14 architects from Finland, Danmark, Northway, Sweden, Turkey and China. As Roto, Law, Vermeeren and Hoonhout (2010) stated that “UX may change when the context changes”. This means the needs that architects had for 3D printer might be completely different from any other industries. Therefore, the following research aimed to uncover the requirements and expectations of architects, inquiring their needs from inside (Ospina,2004; Evered & Louis, 1981).

Methods:

The interview with foreign country users was conducted by Skype video meeting.

The face to face interview was applied during the interview with local architects.

Goals:

Defining the architect’s requirements towards 3D printers, including their previous experiences and further expectations.

Trying to understand the working processes of their daily work and to find out how 3D printers can benefit their work.

Figure 6: Conducting the interview with one of the architecture firms

Results:

Previous experiences: The interviewees can be categorized into those who had used 3D printers before and those who had not used 3D printers. ALA, JKMM and MAD (Beijing) had their in-house 3D printers. Among them, ALA had two consumer-level FDM 3D printers in their office, but they only used them a few times, then those machines had been placed in the storage room. Besides, JKMM had a small commercial level 3D printer, but due to its size limitation, they did not use it oftentimes. Finally, although MAD had their in-house 3D printers as well, they preferred to use CNC instead of 3D printers because the CNC cost was affordable in China and it was faster. All in all, these architect firms seemed did not have a huge preference for the 3D printer.

On the other hand, part of the remaining architect firms ordered 3D printed prototypes from 3D printing service providers when they needed to. The rest of them had never used a 3D printer or ordered a 3D printed part. However, it was interesting that compared to those firms with in-house 3D printers, architect firms who lack experience with 3D printing had more willingness to own a 3D printer, and their attitude towards 3D printer was more positive. In general, the requirement and expectation of architects matched with our initial hypothesis.

The challenge of using 3D printer: For those three architecture firms in the interview who had their own 3D printers. they claimed that the machines they had were difficult to use. The issues are listed below:

1. The clogged nozzle was the most troublesome factor.

2. Having difficulties to start the printing process ranked the second.

3. They also complained that the time spent on maintaining the machine was long, which increased the cost of the projects.

4. One of the interviewees even said their in-house machine broke down time to time, causing them to start using laser cutter instead.

5. Architects from JKMM were satisfied with the performance of their 3D printer. However, they mentioned that the most time-consuming task was transferring the 3D modelling file from softwares such as ArchiCad and Sketchup to STL and repairing the faults generated by the file format transforming process.

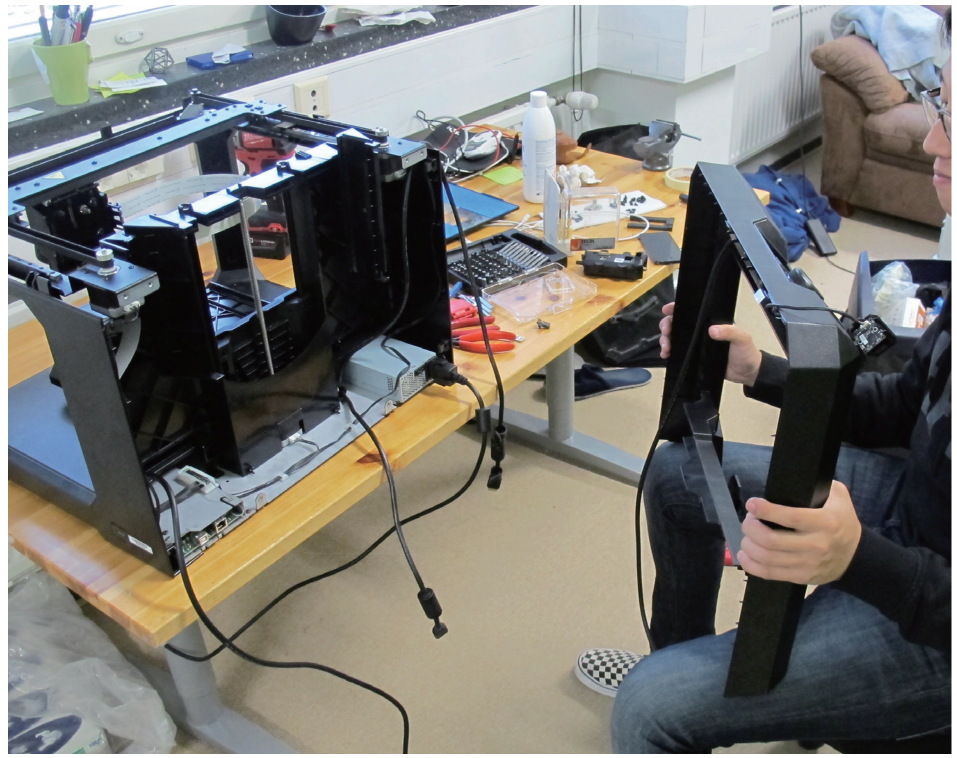


Figure 7: One of the team members was helping one of the architecture firms fix their in-house 3D printer which had been used for only a few times.

Values that 3D print can bring:

Motivating them to make scaled models in the real project: One interviewee provided an example during the interview, he said, "Juhani Pallasmaa mentioned in the book 'The Thinking Hand Existential and Embodied Wisdom in Architecture'(2009) that modeling by hand is superior to 3D printing as one is able to create an architecture that is 'experienced' and 'felt'. However, in the real world, this is very far from the truth". He further claimed that " Architecture firms operate on tight design cycles and deadlines that do not allow a firm to invest days on making a scaled model. If you want to iterate many designs, you will be modeling by hand for plenty of days and this is the reason why most architects do not make scaled models".

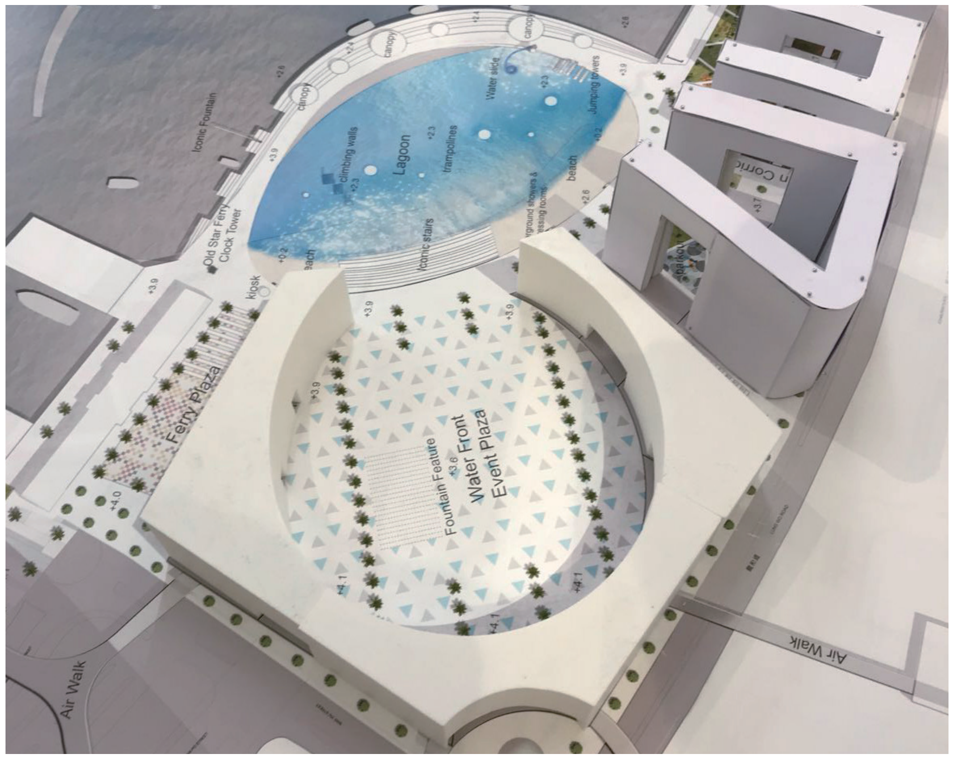


Figure 8: The hands-on prototype from one of the architecture firms.

Complex form exploration: Others believed that the property of AM technology empowers 3D printer to print any shape without being limited by the complexity. In other words, the 3D printer has the capability to make the organic designs which cannot be achieved by traditional prototyping approaches or CNC. This can explain that leading architects such as Foster & Partners and Zaha Hadid have committed to exploring the use of these technologies in upcoming projects.

Figure 9: 3D printed architecture prototype.
Source: https://www.aecmag.com/technology-mainmenu-35/1400-news-3d-printed-a-zha-skyline

Present different concepts to clients in the early stage: Architecture firm Serum explained that it was important to communicate with the clients during each stage of a project while showing the scaled prototype was one of the best ways to enable clear communication. 2D drawing sometimes cannot reveal all the perspectives of a design which might cause misunderstanding for the following stages.

In addition, in the early stage, it was important to show several concepts to the clients, by explaining the ideas behind each concept, clients can understand the design better. The point in this stage was not to show any details to the clients, but only the general forms. So the scaled models should not have colors and materials because these details will distract clients' attention. 3D printer was thereby very meaningful in this stage.

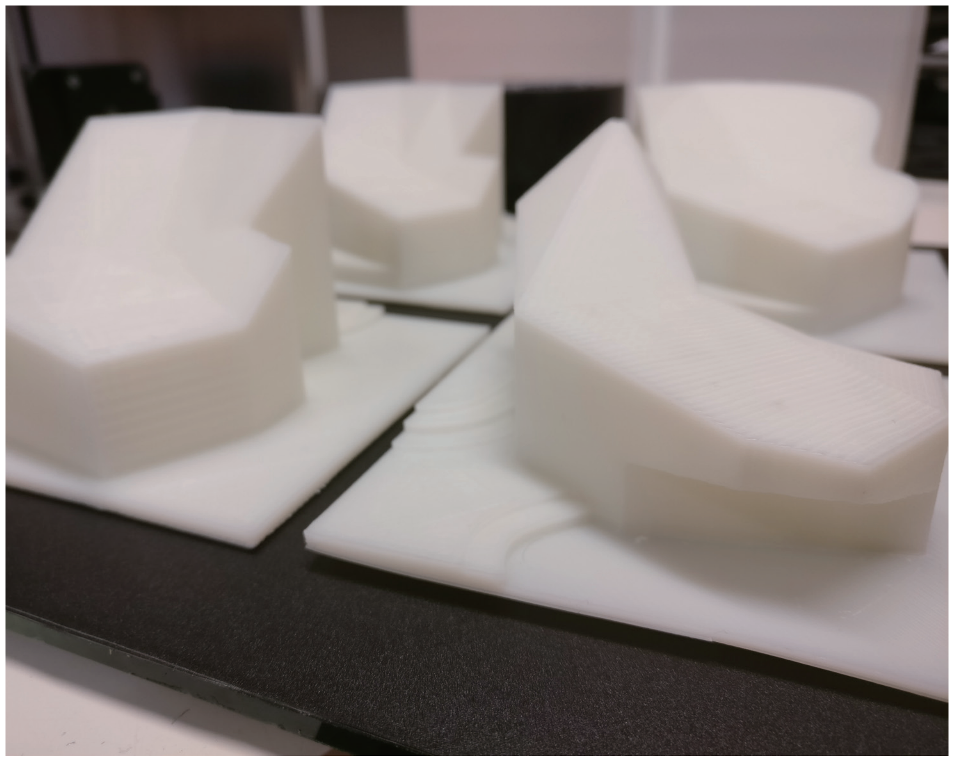


Figure 10: 3D printed prototype for concept discussion internally.

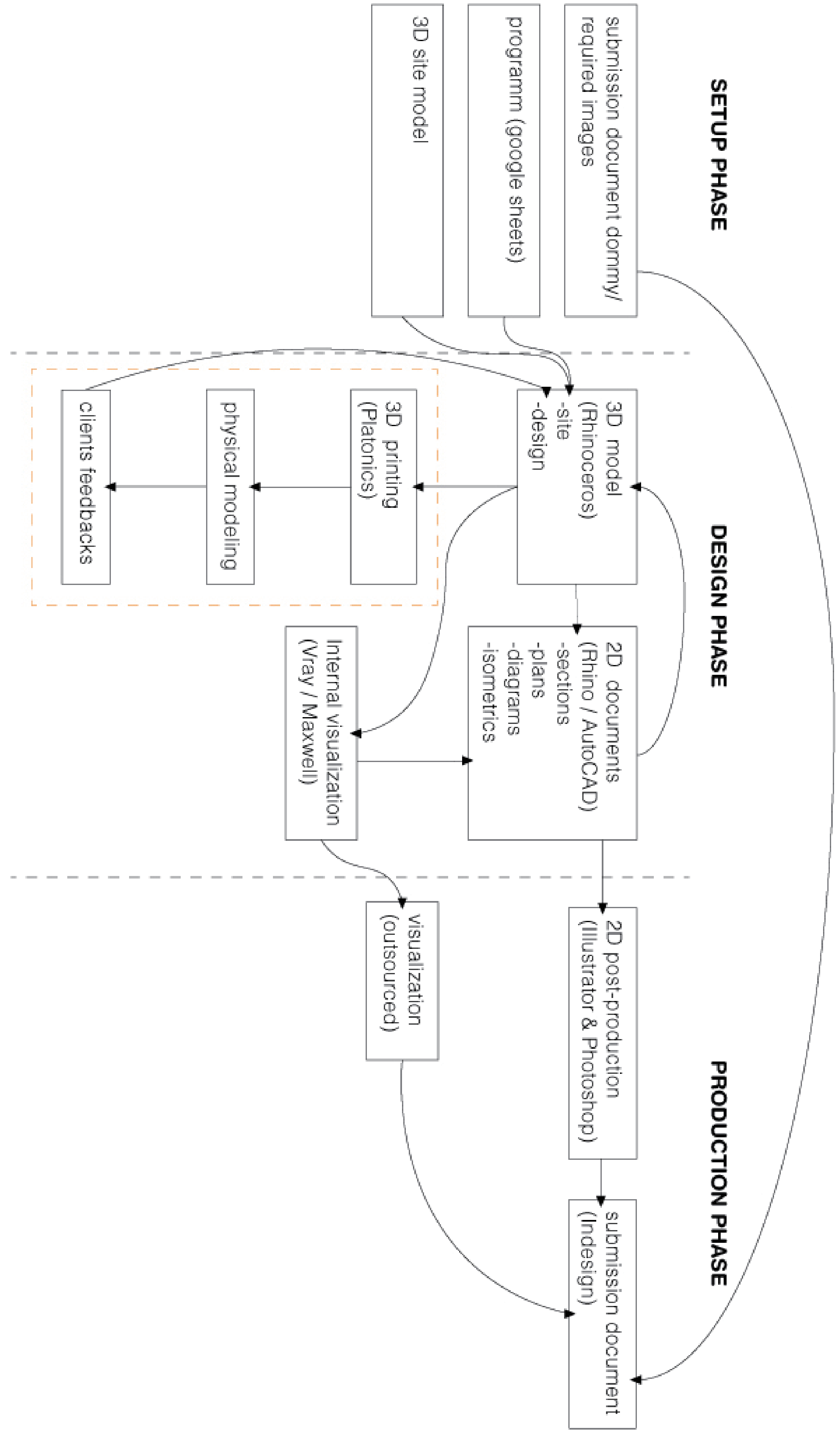


Figure 11: The value of 3D printer in Architects' working process, provided by Serum

3.2 User Research

Strategically, the user research was the next stage right after customer development. In fact, these two steps overlapped. Besides, the user research can be considered as a part of the in-depth research and it went beyond customer development because it further investigated the user requirement for the product design and development. The methodologies used in this step including expert interview, fieldwork observation, online research and workshop. (The workshop was more related to conclude the key features of the 3D printer, therefore, it will be explained in chapter 4).

The expert interview was about to gain professional insights about 3D printers from experts.

Fieldwork observation enabled me to closely watch the users, experiencing the frustration as if I was that role. This made me understand the importance of improving 3D printer usability.

Online research enriched our knowledge about the reasons causing the annoying problems in 3D printers. Some of their solutions were also inspiring.

3.2.1 The expert interview with FABLAB managers

One of the most constructive processes of the user research was the expert interview with Fablab manager Solomon and Jason at Aalto University. The venue of the interview was at Fablab where the managers were working at. It was constructive because first of all, Fablab supports the most 3D printing requirements for all the students who study at Aalto University, the responsibilities of a Fablab manager is to provide guidance and support for all the users. Therefore, Solomon and Jason shared their rich and first-hand experiences with me. Just like Dorussen, Lenz and Blavoukos (2005) stated that the expert interview is specially designed for researchers to obtain reliable data because answers are given by interviewees with high competence. Secondly, all the 3D printers located in Fablab were under the management by managers, they had to repair and deal with anything happened to the 3D printers. During the interview, they recommended me several online platforms that they often used. The information provided on those platforms was very inspiring for the project.

Below are the relevant information obtained from the interview:

1. A booking system was applied to keep the Fablab 3D printing service in order. However, in reality, the reserved time slots often were not feasible due to inexperienced users who had to be taught about how to use 3D printer, for example, giving instructions on how to do the settings, or teaching them converting printable STL files. Sometimes, they had to redesign their files to make them printable. All of these would confuse the booked schedule.

2. “Things will get complicated especially when 3D printers have problems.” said by Solomon. He pointed out that if a printer could not work properly or breaks down, the entire schedule on the booking system had to be changed, and the time for the repairing work was unpredictable. Two most common problems were the nozzle of the 3D printer gets clogged and the warping issue. Sometimes, he could repair it by himself,

while sometimes, he had to call for the service or even sent the 3D printer back to the suppliers and this process might take as long as two weeks.

3. Another technic challenge was about starting the print process. “We always suggest our students that they should at least stay here until the first a few layers were done” mentioned by Solomon and Jason, “the first layer of the FDM 3D printer is very crucial, users need to make sure the filament sticks to the print bed nicely, otherwise, the print will not be successful and it will cause a severe consequence”.

4. In order to help me understand the challenges, they suggested me to visit 3dhubs, Thingiverse and Thomas Sanladerer Youtube Channel to get deeper understand about the current problems of 3D printer and the corresponding improvement solutions. These were extremely helpful for us to develop the product.

3.2.2 Fieldwork study in Fablab

A fieldwork study was carried out in Fablab in order to understand the challenges of using 3D printers in the real-life context, this was also suggested by Solomon. The actual fieldwork observation lasted for two days in Fablab. However, a weekly follow up session was implemented in order to get a holistic understanding of the complexity of the real-life condition.

The fieldwork study proved that the complexity factors would increase the difficulty in managing the 3D print workshop, in which the most important obstacle, in general speaking, was the reliability of the machine. The reliability issue could be categorized by two technical problems which are sticking problem and the clogged nozzle.

A frustrating experience of using a 3D printer of a design student: One of the most impressive cases during the fieldwork study was from a design student who wanted to use a 3D printer to finish her 3D prototype which was assigned by a jewelry design course. The student brought her STL file and chose to use an FDM printer to print the prototype. The Fablab manager provided her with a brief introduction about how to use the printer and helped her to set up the STL file and the 3D printer. The student indeed took Solomon's suggestion that waiting until the first layer was done. Unfortunately, the first layer of that print had never be done due to the sticking problem.

We tried several attempts including using 3M blue tape and applying glues, but neither of them worked. Adjusting the four screws underneath the printing bed was also tried in order to calibrate the Z-axis. However, this calibration work requires relevant professional skill and it often takes users a relatively long time. The student had to do this step by herself as the Fablab manager had to provide help for other students simultaneously. The student repeated the starting process for more than ten times with manually calibrating the printing bed. At the beginning, she gently adjusted the screws underneath the build plate and moved the X and Y axes of the printer for leveling; however, several times of the unsuccessful calibration took her patience away, then, she even attempted to use her finger to press the first layer in order to let the filament stick to the printing bed. This action was stopped by me because some 3D printers have the bed heating feature which could hurt her finger, not to mention the nozzle is nearly 200 ºC.

The student spent about one hour on trying to start her print and eventually she gave up. Her depression could be seen on her face and she mentioned that it was not the first time she occurred to this problem, but that day was the worst experience she had ever met. At the end of the day, Solomon spent another hour after his official working hour ended on fixing that 3D printer.

The worst clogged nozzles: After the two days actual fieldwork study, one day I received a phone call from Solomon, asking me to visit Fablab to witness the most terrible clogged nozzle that happened in Fablab. Unfortunately, when I arrived at Fablab, the clogged nozzles along with the entire printing heads had been taken away by the service provider because those nozzles had to be sent to the repair shops for the maintenance.

Solomon told me that the clogged nozzles happened to two printers and it was caused by the same project. It was difficult to find out whether it was the printers' issue or the STL file had the fault causing the nozzle to get clogged, but the case was that melted filament formed a huge ball with the size similar to a ping pong which stuck on the nozzles and because it was too big so that the melted filament was spread to the entire printer head. That is why the service provider had to take the entire printing head away. Although this case was an extreme example, it proved what Solomon said in the interview.

3.2.3 Online information collection

"The internet is a social phenomenon, a tool, and also a field site for qualitative research"(Markham, 2010, p.1). As mentioned previously that the AM technology has been becoming popular, enthusiasts have formed many communities online which provide all sorts of information about 3D printing technology. Therefore, while conducting the fieldwork study at Fablab, I also carried out the online research.

3dhubs, Youtube, MatterHackers and Thingiverse were selected as the main platforms to collect information based on the recommendation given by Solomon and Jason. It is worth mentioning that the information provided from the online platform might not be as accurate as that provided on the academic papers. Therefore, I evaluated them and figure out those were valuable for the project with the support from one of the team members.

The problems about using 3D printer revealed from online platforms were similar to those had been found out from the interview and fieldwork observation. In addition to the problems, the online research enabled us to have a more profound understanding about the reason causing these issues, and some solutions designed by amateurs were very creative which inspired us in the product development stage. Below I will explain the most important findings from the online research, they are mainly about the issues that 3D printers had in 2016 and the reasons causing these issues.

Clogged nozzle: Similar to an inkjet printer which has the problem that dried ink blocking the nozzle, FDM 3D printers also have the same problem. The material needs to be heated and liquidized so that it can be extruded from a nozzle to the printing bed. However, several reasons can lead to a nozzle get jammed and the main reasons are, for one, unmeltable impurities of the filament accumulate and form an object which blocks the nozzle, for another, low print temperature results in the unmelted filament block the nozzle, or the gears of the extruder (Richter, 2017).

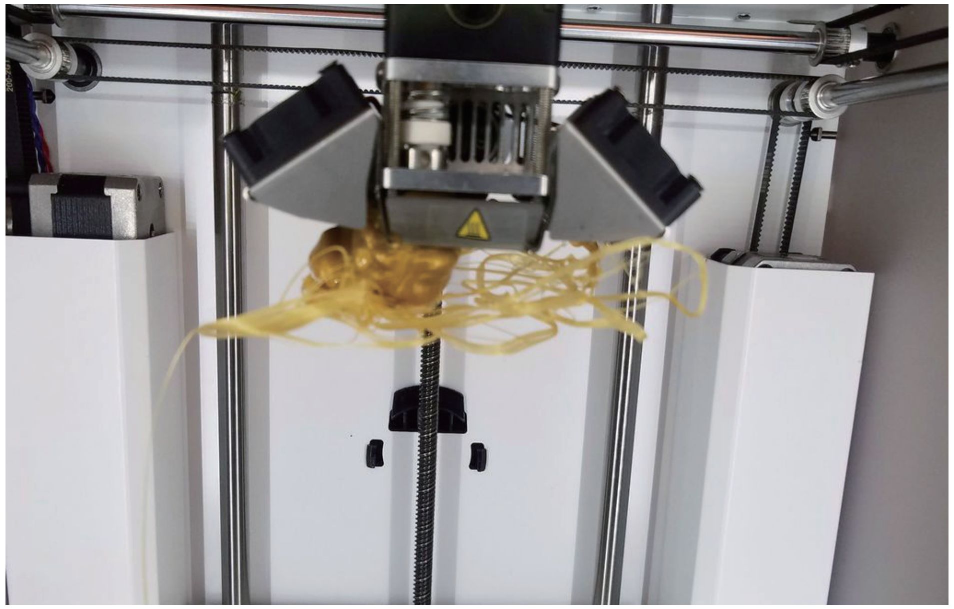


Figure 12 shows the nozzle of a 3D printer gets clogged.
Source: https://www.instructables.com/id/Cleaning-a-Ultimaker-2/

First layer issue (Warping & Unders-extrusion) caused by incorrect bed-leveling: The first layer issue was one of the most often mentioned problems during online research. Actually, the first layer of the 3D printing process is similar to making a solid foundation of a building, without a proper first layer, the print will be likely to fail. If the nozzle is too far or too close to the printing bed, the first layer will have problems. To be specific, if the distance between the nozzle and the printing bed is

too big, the extruded filament will not stick to the printing bed very well, which will result in warping problem. Conversely, if the nozzle is too close to the printing bed, there will not be enough room for the filament to be extruded properly, which will cause under-extrusion (Fordyce & Me3D, n.d.; Tyson & Rigid.ink, n.d.). This problem will further cause the extruder to get clogged because if the gears of the extruder cannot push the filament to move forward while spinning, the gears will start to grind the filament, then, the ground particles will fill the teeth of the gears.
The mentioned issues are caused by improper bed-leveling. Specifically,

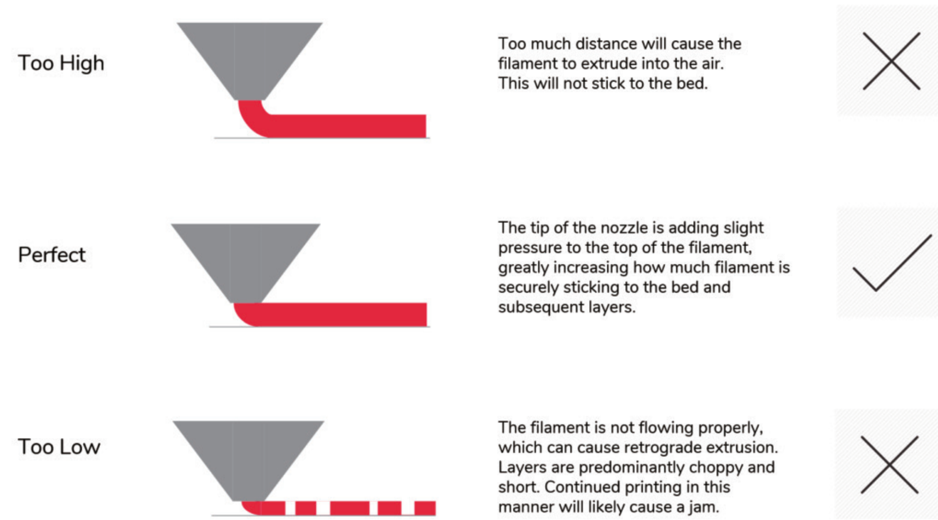


Figure 13 illustrates the results of the different distance between the nozzle and the build plate.
Source: https://support.me3d.com.au/hc/en-au/articles/333757004395-Nozzle-Height

The imprecise bed-leveling will result in an uneven gap between the nozzle and the bed when the nozzle is in different locations on the bed. Without the correct and consistent gap, the warping and the under-extrusion will likely to happen because the filament cannot stick to the build plate properly.

Clogged extruder: Clogged extruder was another main issue that was often mentioned in all kinds of 3D printer communities. As those have been discussed previously. Incorrect bed leveling, the clogged nozzle can all result in this issue.

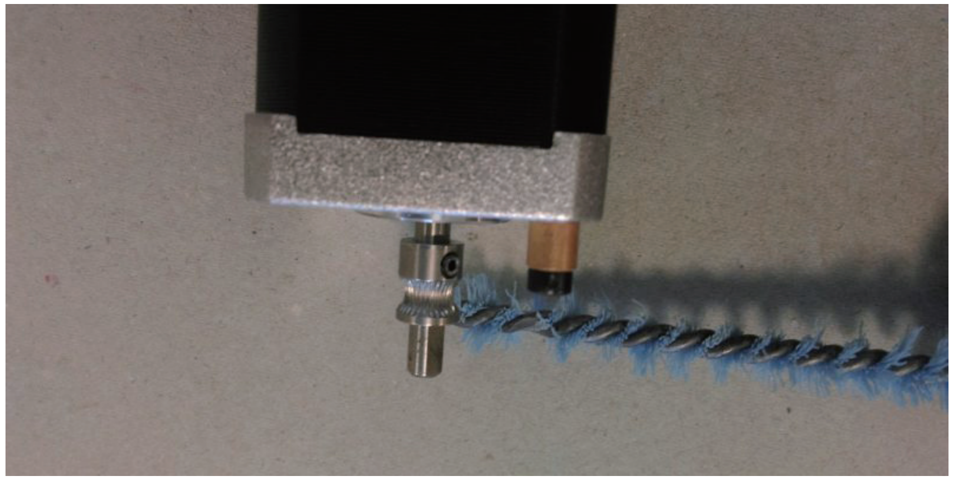


Figure 14 shows the teeth of gear of the motor are filled with filament particles.
Source: https://emvioeng.com/tag/extruder/

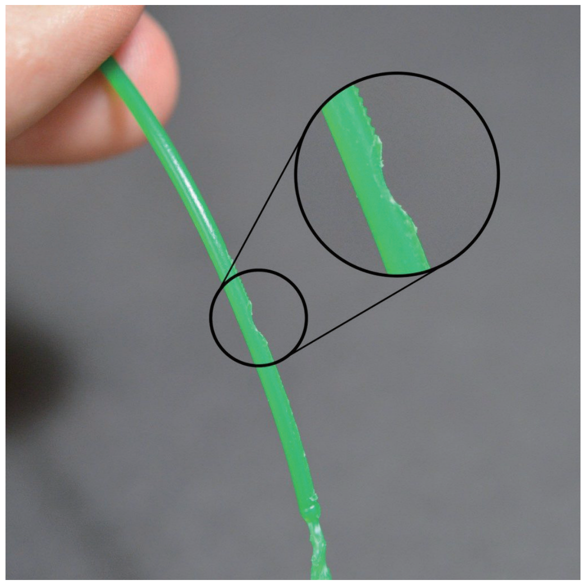


Figure 15 shows the grind marks of the filament.
Source: https://www.simplify3d.com/support/print-quality-troubleshooting/grinding-filament/

3.3 Reflection about the customer development

Product positioning plays a vital role in marketing, it is a decisive factor in the future direction of a product (Richards & Chron.com, n.d.). If a product is failed to be positioned to its most matching customer groups, the project will be negatively affected. Therefore, I can hardly deny the constructive contribution that the customer development brought to the project. However, as I review this project, just because of the importance of customer development, I believe that we made the mistake which was the customer development was drawn a conclusion too roughly and too early. This mistake directly resulted in the difficulty in raising funding at the end of the project.

Defining the potential customer is indeed essential no matter for a famous enterprise or for a startup company because a product needs to be located in a suitable space to maximize its value. Hence, customer development is a good method which is helpful for identifying and narrowing down the marketing direction. However, before making a decision, an evaluation about whether the defined customer groups are proper or not and are the data reliable and well-rounded enough for supporting the following development of the project should be carried out.

For example, the factors supported the team to make the decision that taking Architects as the target user group were, on the one hand, their requirements for making tangible prototypes which can be done by 3D printers, on the other hand, they were lack of experience in using 3D printers. These made us believe that we found the empty of the market. Therefore, we rushed to fill in this vacancy. We believed that as long as we could understand the requirements that Architects had for 3D printers and develop the project according to their needs, the project would be successful.

However, the risk and the effort of developing a product targeting the immature customer group are far beyond our imagination. In fact, the acceptance that customers have for a product sometimes has to be realized by a long term strategic education. If a company does not have the resource to take the educational responsibility, the product will likely to fail. For example, IKEA had to adjust its DIY service strategy in India in order to adapt to the local culture that they tend to outsource the household services to the local cheap labor (Tandon & Quartz|INDIA, 2018). Noticeably, the difference here is that for big companies like IKEA, they have abundant resources and they are influential enough which allow them to invest in money and time to foster a buying culture in a new market, while for startups, it is unlikely to be possible.

Furthermore, whether the requirements of other user groups should be neglected or not after finding out the targeting customer group is another factor that deserves to be discussed. Hardly can anyone deny that the factors attribute to the success of a startup have to include a well-rounded customer discovery and customer validation. In my opinion, all of them have to be based on the principle of being flexible. It is obvious that this project prematurely limited itself to the architects' industry which disobeyed the principle of being flexible. This led to incomplete user research because the data and the requirements obtained from inexperienced users had less product development value in terms of the technical aspects. The technical aspects here refer to the advanced professional functionality in consumer-level FDM 3D printer industry. For instance, in 2016, other than solving bed leveling and clogged nozzle issues, printing double materials (a water dissolvable support material) was a prospective function for consumer-level FDM 3D printer. However, the requirement for this function can hardly be obtained from the inexperienced users, only those professional users or 3D printer geeks can point out the incomparable value of developing the double material function. Obviously, due to we limited our only target user group to be architects in the early stage and the user research was conducted under the frame formed by the customer development. Therefore, the research about the topic that whether there were other important functionality requirements or not was not holistically carried out. This also caused the product to lose its competitiveness in terms of the function aspect compared with the leading products available on the market such as Ultimaker 3. Even if at the end of the project the team had tried to expand its target user groups in order to increase the sales and gain more investments, the consequence of neglection towards other industries at the beginning eventually was appeared, it blocked the raising of investments.

Based on those have been discussed above, I tend to believe that as startup companies, market positioning is definitely important, however, being open and being flexible should be the principles that have to be kept in mind all the time. Balancing focus and exploration is very important.

Chapter 4

Product Development & Key Features Prototyping

This chapter will mainly focus on the description of the corresponding solutions generated from the previous researches. These solutions finally formed the prototype. It is worth mentioning that during the product development process, I made some mistakes which caused the delay of the development and increased the difficulty of the prototyping, this will be stated in this chapter as well. In addition, the reflection based on the mistakes and applying the improved method to the development of other features will be explained.

4.1 User Experience workshop

After the intensive user research, there was a workshop organized by the project team. The purpose of the workshop firstly was to provide us with opportunities to observe users with different backgrounds to use 3D printers, therefore we can understand the requirements of users in a more well-rounded context. In addition, we aimed to collaborate with one of the participants specialized in UX design to sort the research data obtained from the previous research, in order to crystallize the key features that the 3D printer should have.

The workshop had the morning session and the afternoon session. The former focused on letting users finish the given tasks and express their thoughts. The latter was about analyzing the data. The participants involved two design students, one mechanical engineer students from Aalto University and one participant without any design background.

During the morning session, each participant was required to use 3D printers to print an object that they wanted to have. The 3D model could be either those obtained from online or their own 3D modeling files. Each step was observed by the project team members. Team members were also responsible to provide assistance when participants faced difficulties. After all the participants had finished the tasks. They were invited to answer a pre-designed questionnaire.

The afternoon session was to sort and analyze the data obtained from the morning session, the previous customer development and the user research work. Through the analyzation, we listed as many defects as possible in terms of the consumer level FDM 3D printers as well as the improvements that could be done for the 3D printer. Then, the team decided to develop the following features for the 3D printer:

- Swappable nozzle

- Auto bed-leveling

- STL auto converting & auto fixing the broken parts

- IoT (Instead of using the SD card to transfer the STL file to the 3D printer from computers, the 3D printer has its own server which enables users to access to the 3D printer through their computers.)

- Simplified software

This workshop played a constructive role in terms of concluding the previous researches. It not only enabled us to understand the users in the real context but also helped us internally figured out the main features that this product should have. The workshop signaled that the project started moving to the actual development stage.

This thesis focuses on the development of Swappable nozzle and Auto bed-leveling even though all the listed features had been developed in this project.

4.2 Benchmarking

Along with concept generating process, I carried out a benchmarking which aimed to understand the advantages and shortcomings of current existing products so that we could take them as references to evaluate our concepts, the benchmarking mainly focused on the build plate leveling solution and nozzle replacement idea.

4.2.1 The auto bed-leveling benchmarking

Inductive sensor auto bed-leveling: Back to the year 2016, there were not so many sophisticated solutions about build plate leveling that could be found on the consumer level 3D printers. Installing an inductive sensor on the printer head was one of the relatively precise solutions that had been used by a few companies, this included Type A 3D printer.

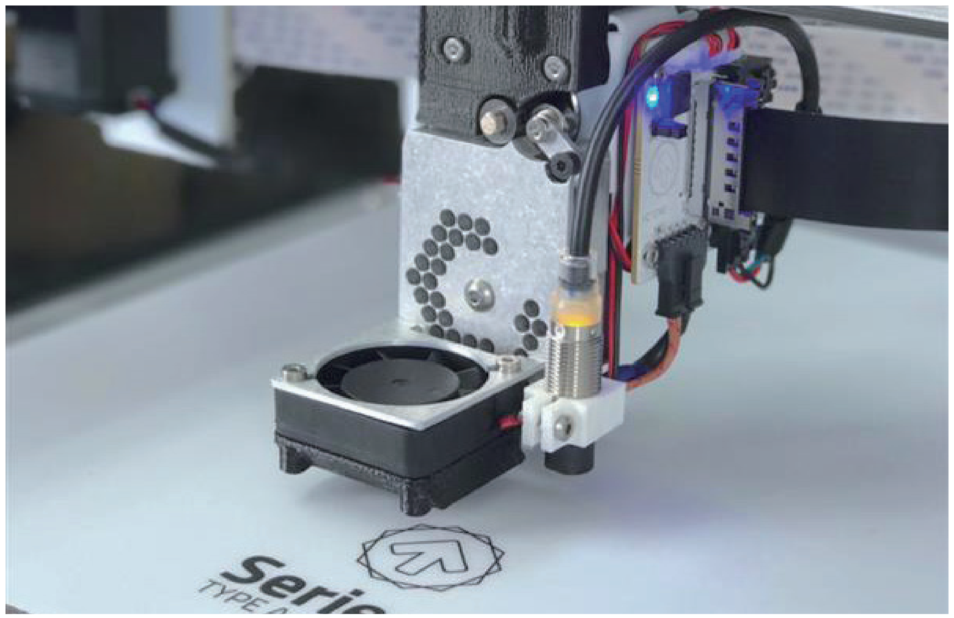


Figure 16 shows TYPE A 3D printer uses the inductive sensor for bed-leveling
Source: https://www.3ders.org/articles/20170426-type-a-machines-improves-series-1-pro-3d-printer-with-buildtak-flexplate-and-adaptive-auto-leveling.html

The figure is about the bed leveling solution of Type A 3D printers. It attaches an inductive sensor to the printing head. According to Simplify 3D(n.d.), "the inductive sensor will probe several locations on the build platform to calculate the distance between the nozzle and the bed at each point. This data is then used to compute the actual orientation of your print bed with respect to the nozzle's movement in the XY axes. While printing, the printer's firmware will actively use this information to adjust the nozzle position as it moves across the bed. So even if your build platform is slightly unleveled, the firmware will make small adjustments to the Z-axis while you print to ensure the nozzle is always the perfect distance away from the print bed."

Although the inductive sensor can automatically compute the distance between itself and the build plate, which is helpful for the bed leveling process, this method has its disadvantage. To be specific, as the inductive sensor and the nozzle are two separated parts, the assembly clearance and fabrication tolerance between the nozzle and the probe of the inductive sensor will require users still need to manually set the offset parameter in the firmware so as to make sure a suitable distance between the print bed and the nozzle, not to mention the size of the nozzle differs. In other words, the inductive sensor knows where is the build plate, but it does not know where is the nozzle. Therefore, the inductive sensor cannot be an essential solution.

Manual bed leveling: Manual bed leveling was the most common method in consumer lever FDM 3D printers, with Ultimaker's spring screw approach used the most. By adjusting the spring screws underneath the build plate, the print bed can be leveled manually. Normally, the user needs to insert a piece of paper between the nozzle and the build plate time to time, making sure there is an even gap distributed in different locations of the print bed.

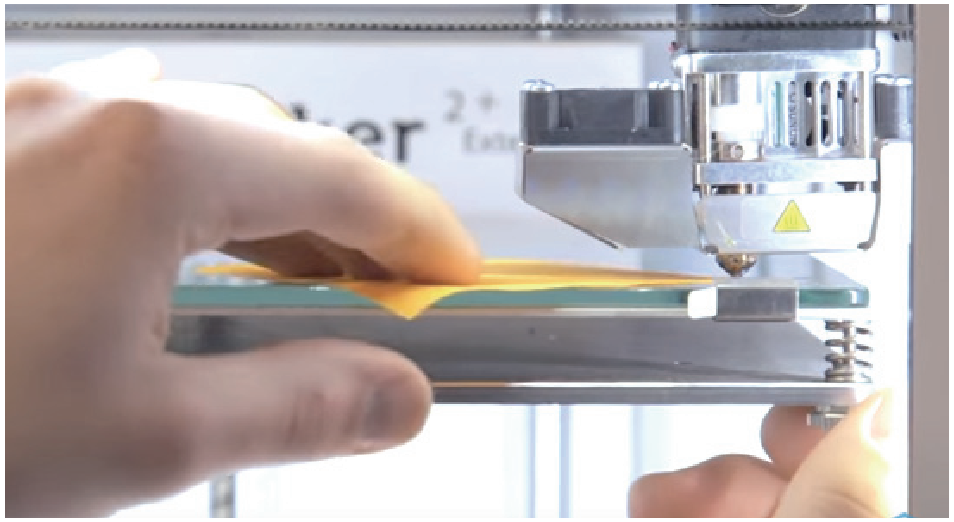


Figure 17 shows the manual Z-axis calibration process
Source: https://www.matterhackers.com/articles/3d-printer-bed-leveling

The drawback of this method is the intensive labor work. Users have always been complaining that manually adjusting the build plate is extremely time-consuming, and it also requires the user to be highly skillful.

Lulzbot circuit auto-bed leveling: Another auto-bed leveling method was found on Lulzbot 3D printer. According to Piercet(2018) posted on Lulzbot forum, on the build plate, each corner has a leveling washer which plays as the switch to close a circuit once the nozzle touches the washer. The software will calculate the distance that the Z-axis moved in order to trigger the completion of the loop, thereby, giving the real-time compensation of the Z-axis during the printing process.

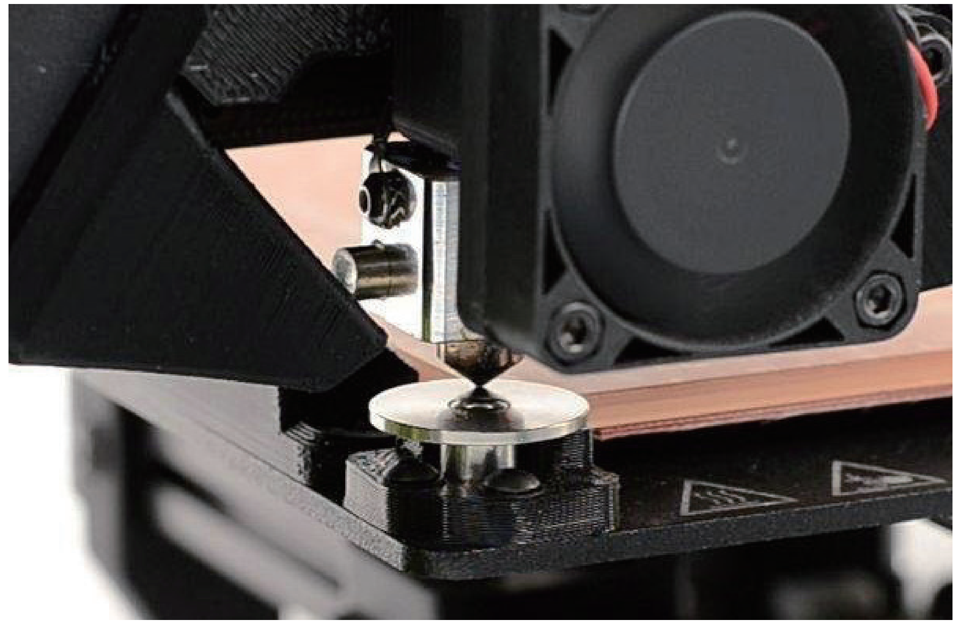


Figure 18 shows the Lulzbot 3D printer uses the metal washer to help the Z-axis calibration
Source: https://www.amazon.com/LulzBot-Mini-Desktop-3D-Printer/dp/B00S54E1AI

This solution was one of the greatest methods to make sure the accuracy and reliability of the auto-bed leveling since it achieves a real touch between the nozzle and the build plate which excludes the possible inaccuracy factors caused during the assembling.

4.2.2 Swappable nozzle benchmarking

MakerBot Smart Extruder+: In the year 2016, Makerbot was one of the most successful 3D printer companies due to its pleasing features. Among them, the Smart Extruder+ was very remarkable. It is called Smart Extruder, but technically, this component contains both the extruder and the nozzle together. This component is connected to the main body of the

3D printer by the magnet and the pogo pins which makes the swapping process very easy.

Figure 19 shows the MakerBot Smart Extruder+
Source: https://shop3d.ca/products/smart-extruder

Despite the advantages, this Smart Extruder+ was relatively costly. Once the nozzle got jammed, users would still prefer to disassemble this component and spending time on repairing it because of the high price.

4.2.3 Inadequacies of the benchmarking and reflections

The benchmarking was necessary for the product development because it broadened our perspectives, enabling us to study those existing solutions and thereby, accelerating our speed for the product development. According to O'Dell and Grayson(1998) and Elmuti and Kathawala (1997), a key function of doing benchmarking is that through this, organizations will reduce the risk of reinventing the wheel. However, the real world is that competitors will not reveal their newest technologies or features until they launch their products. This increased the difficulties of researching competitors.

Hence, I have to admit that this benchmarking was not very successful because I did not make the research about other 3D printer companies deeply enough, especially I failed to constantly pay enough attention to their latest action in the market. For example, in the benchmarking of the swappable nozzle concept, I only conducted the research targeting the existing products on the market and by which I generated the conclusion that our concept was unique enough. However, during the process that we were developing this concept, Ultimaker launched its newest product Ultimaker 3 which had already integrated this feature. This was a significant strike for the uniqueness and core value of our product.

If I could have the opportunity to do the benchmarking once again, I would arrange the benchmark more systematically and let every team member in the startup participate in. “Benchmarking is first and foremost a tool for improvement, achieved through comparison with other organizations recognized as the best within the area. The philosophy of benchmarking is that one should be able to recognize one's shortcomings and acknowledge that someone is doing a better job, learn how it is being done and then implement it in one's own business(Bhutta & Huq, 1999; APQC, 1996)”. As a startup company, a holistic benchmarking can be extremely useful because it provides the opportunity for a small team to crystallize the advanced knowledge from the market and to explore their survival spaces. Therefore, every team member should be motivated to participate in the benchmarking.

In addition, there should be a clear goal of the benchmarking and the benchmarking targets should be clearly defined. The focus should not only be the existing products. What is more, understanding the trend of competitors is extremely important. That is to say when doing the benchmarking, existing solutions equals to the past which is important for sure, but understanding the future is more valuable. Therefore, I should have tried to gather the news about the trends of each competitor from all kinds of channels.

4.3 Swappable Nozzle Design and the Reflection

Designing the swappable nozzle was one of the most important tasks in this project. The nozzle design and development took almost four months from the concept until it was finished. It should have been done faster if there could be a better design procedure. Therefore, not only the concept development process will be explained, but also It is worth to point out the mistakes happened and to reflect it.

4.3.1 Introduction about the idea

The result of the user research showed that the clogged nozzle was one of the most occurred problems in the FDM 3D printer. Once it was broken, the user had to spend a long time to clean the clogged nozzle because the entire printer head often needed to be removed from the 3D printer, this process was complex, and this significantly reduced the 3D printer user experience.

According to Baldwin and Clark (2004), the modularized design can "make the complexity manageable". Therefore, due to the high breakdown rate and the complexity of the repairing process, the initial goal of the nozzle design concept was to modularize the printer head so that users could disassemble it from the 3D printer easily and then carry out the repairing work. Then, if we have a more detailed decomposition about parts of a printer head, it can be noticed that the nozzle itself was the most problematic part. At the same time, from the business and strategy perspective, the nozzle, the hot-end and the heatsink are standard parts which are low-cost. Hence, we decided that the nozzle along with the hot-end and heatsink could be designated to be modularized together as the consumptive material of the 3D printer. Instead of spending time on repairing the clogged parts, the user could simply remove the clogged nozzle and install the new one effortlessly. By doing this, the maintenance time would be dramatically shortened and this service would reduce the cost of using the 3D printer. Taking the case of architects' daily work as an example, the cost of a modularized nozzle was about 15 to 20 euros and it took architect 5 minutes to finish the replacing work. This is more cost-efficiency and affordable than an architect spends one or two hours on cleaning the clogged nozzle considering the hourly salary of an architect could be more than 40 euros per hour.

4.3.2 Conceptualization

After making the decision that the nozzle, the hot-end and the heatsink would be designed as a module, I started to design the corresponding mechanical structures which enabled the module to be easily installable and removable from the printer head. The key of the concept was adding

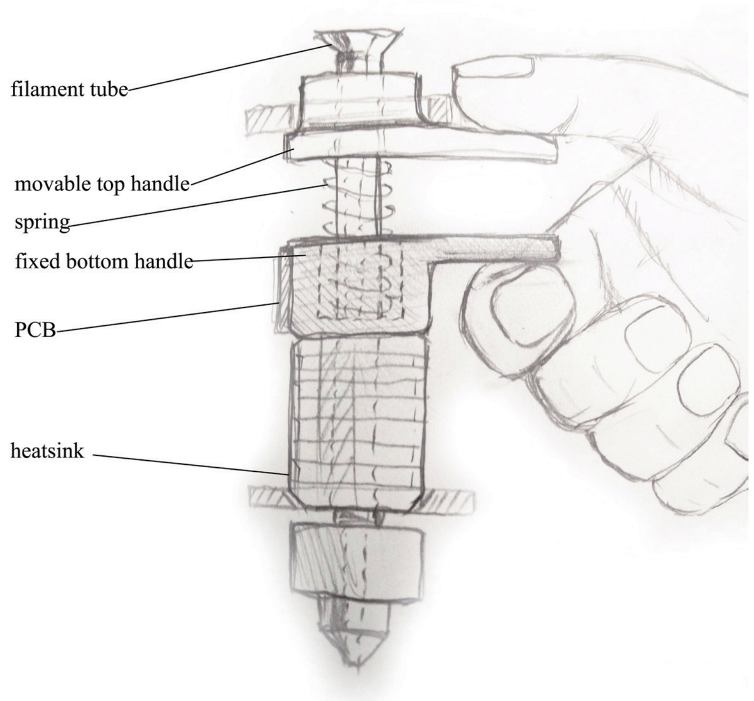


Figure 20 shows the components of the first version swappable nozzle

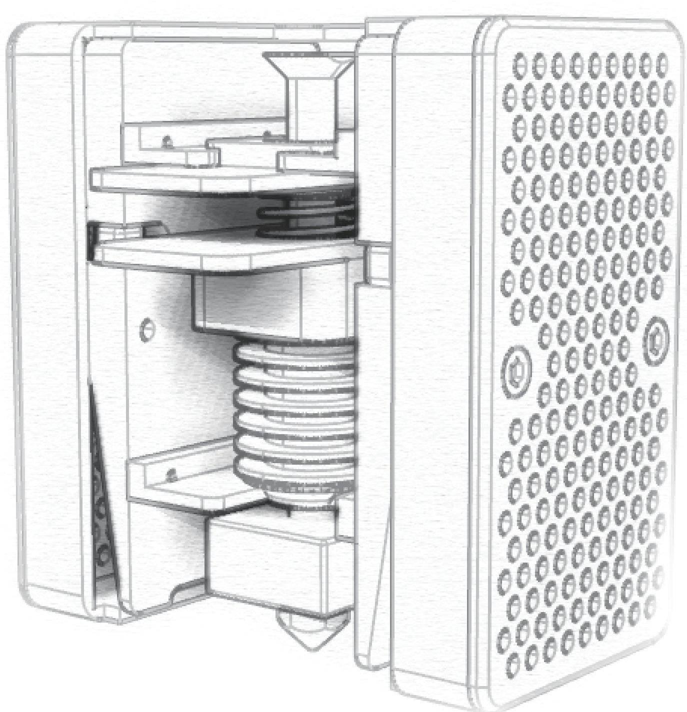


Figure 21 shows the design of the first version swappable nozzle

a pressable spring handle mechanism which contained a movable top handle, a fixed bottom handle and a spring in between these two handles. The top handle could do the linear movement along the filament tube and it was tensioned by the spring. In addition, the PCB board was placed on the front of the module, which contained pogo pins, ensuring the signal transmission.

This concept enabled users to use one hand to operate the handle mechanism. The user could simply press the handle, the spring in between the top and bottom handles would be compressed and the top handle would be moved downwards. Then, the user could insert the module into the printer head housing. The bottom of the housing had a countersunk hole, it matched with the end of the heatsink. This hole could position the module. After the user positioned the module, the handle mechanism could be released, the top handle would be pushed to a corresponding groove by the tension from the released spring. Then the module would be mechanically locked nicely. At the same time, the male part of the PCB pogo pins on the front of the module would connect to the female part PCB pogo pins in the housing.

4.3.3 Prototyping and the unfavorable result

We decided to order a CNC machined prototype right away from China after the concept design was done. The prototype included a set of printer head housing and two sets of nozzle modules, in which the nozzle, hot end and stainless steel hose were standard parts bought from Alibaba, the rest parts were made by CNC. The material was Aluminum with anodized surface treatment.

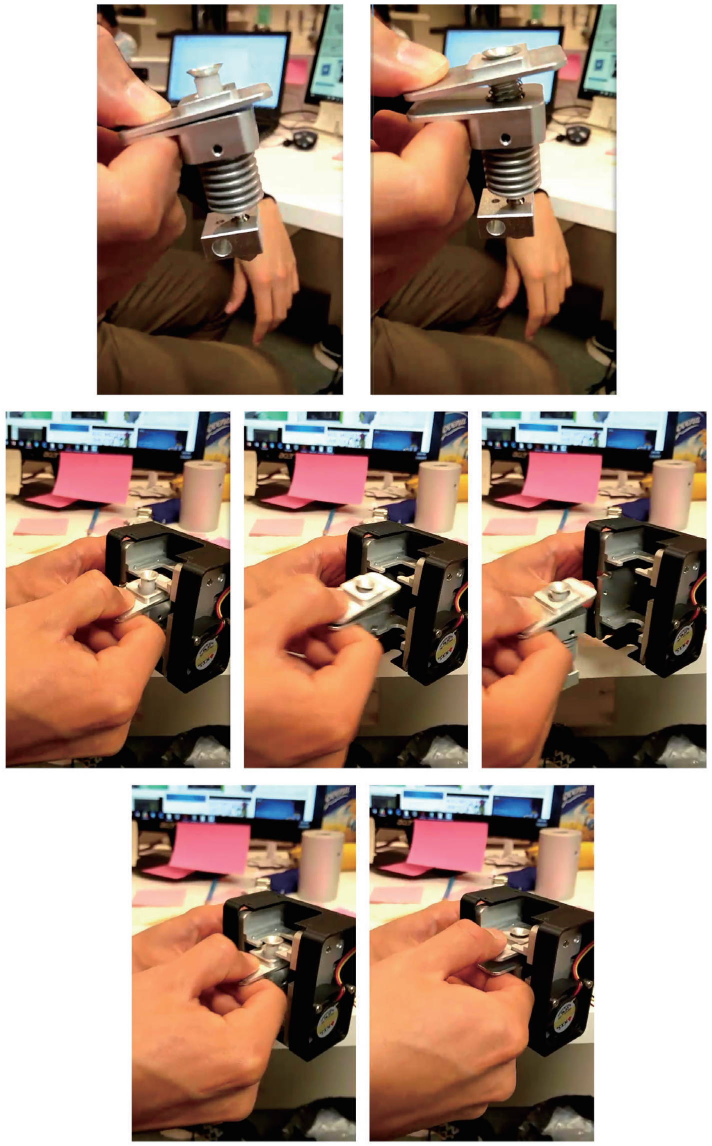


Figure 22 shows the steps of removing and installing the nozzle

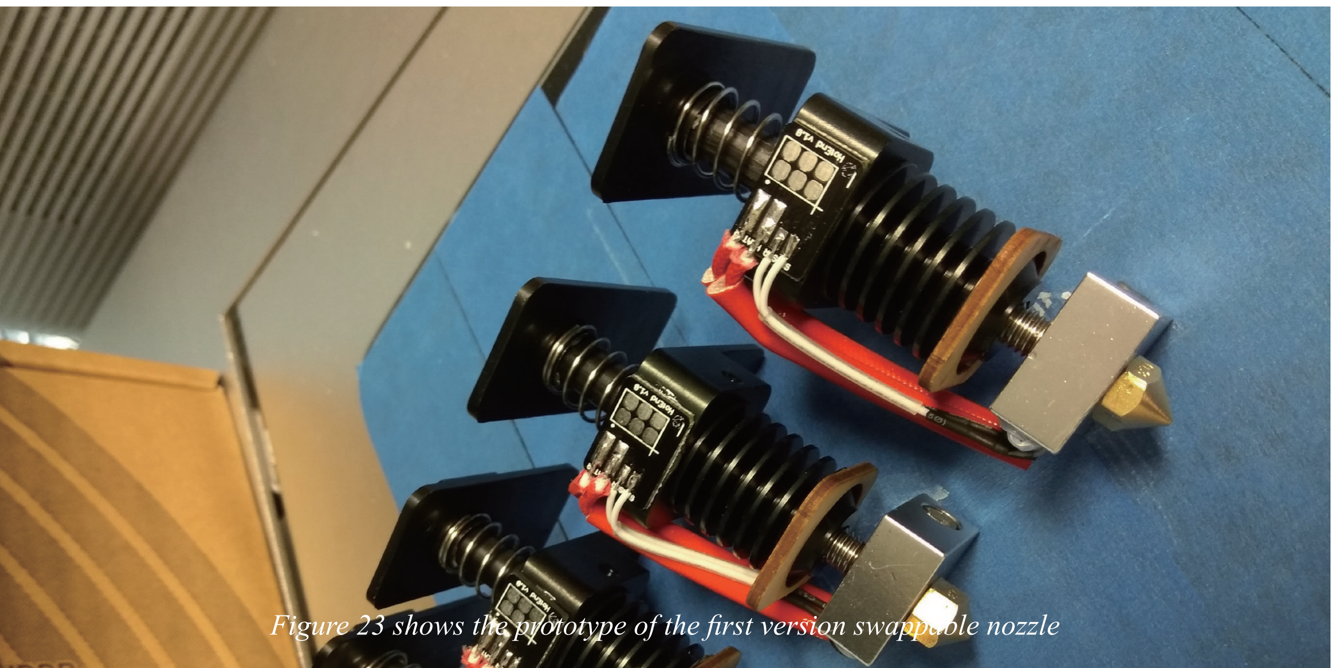


Figure 23 shows the prototype of the first version swappable nozzle

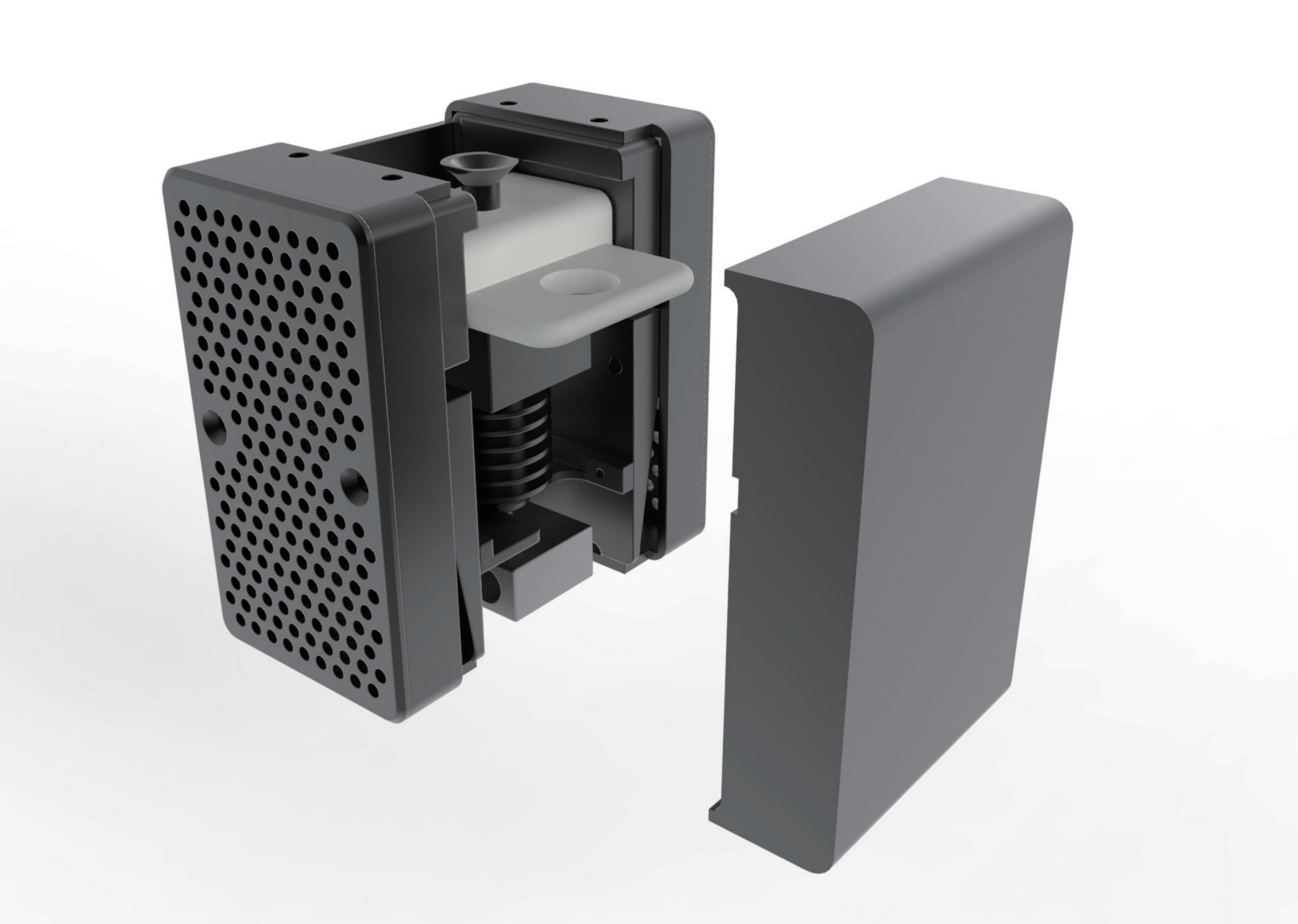
We assembled the prototypes immediately after receiving them from China, then we tested the prototypes, but the result was not good. To be specific, the spring handle mechanism could not work as expected, the top handle could not move along the filament tube when we pressed it downwards. In the beginning, we suspected the reason was the surface of the machined parts were not smooth enough, thereby, we polished them by the finest sandpaper but hardly saw any changes. Then, we covered the filament tube with a Teflon tube in order to reduce the friction between the top handle and the filament tube. Despite this realized the mechanical movement of the design, it required an extreme amount of hands-on post-processing work and the result was still not perfect.

Other than the mechanical issue, the spring handle mechanism had another drawback which was the imprecise connection of the pogo pins. After several times of experiments, we found that the spring handle mechanism enabled the nozzle module to move up and downwards, but this movement would result in dislocation of pogo pin connecting points when the user was putting the nozzle module into the housing. This damaged the PCB boards and even triggered sparks when the female and male parts of pogo pins misaligned.

4.3.4 Swappable nozzle redesign

We spent five weeks on fixing the issues by doing modifications and improvements to the nozzle module. However, the resulted could never reach our expectation. Finally, we had to redesign a new structure.

I gave up the spring handle mechanism, instead, with the support of our



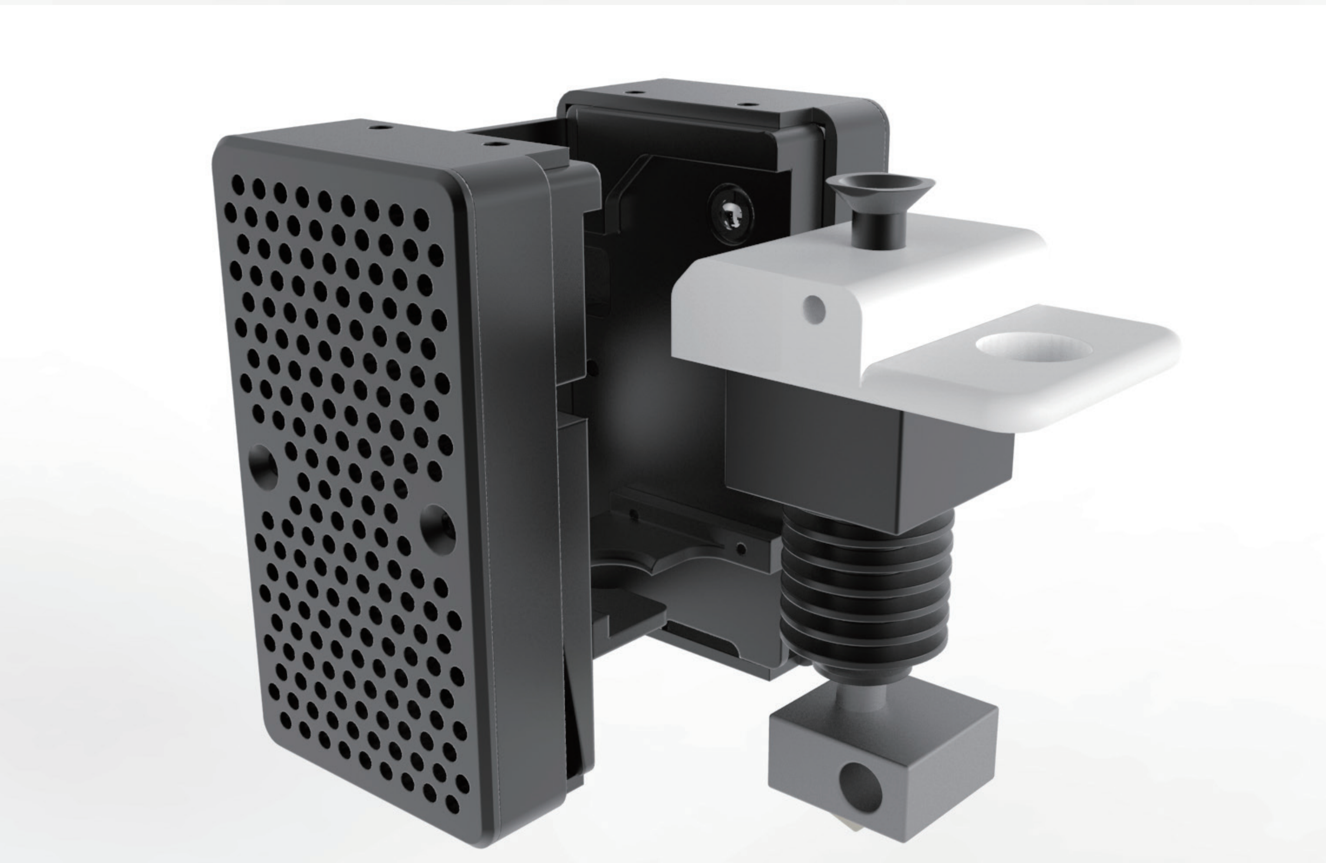


Figure 24 shows the redesigned swappable nozzle concept

Germany contract manufacture Hefter, we used the spring plungers to fix the nozzle module. Specifically, the nozzle module still had a handle structure which gave users easy access to remove or install the nozzle, but there was no movable part in the nozzle module. So the entire design was simplified. The handle of the nozzle module had a positioning hole on each side, they corresponded to the position of spring plungers located on the left and right sideboard of the housing. When the user inserted the nozzle module to the end of the printer head housing along the milled track of the housing sideboards, the steel ball of the spring plungers would lock the nozzle module. At the same time, the pogo pins would connect to each other.

The prototype of this concept was 3D printed. On the one hand, 3D printing could enable us to receive the prototype faster so that we would test the concept earlier. On the other hand, this concept did not require such a high precision fabrication and it could be realized by plastic. We conducted the test after receiving the prototype. The entire assembling process went very well and the result of the test was very satisfying. Meanwhile, the pogo pins worked nicely as well due to every component of the design was fixed.

4.3.5 Reflection

Although the swappable nozzle concept eventually was successfully developed and its usability was more convenient than Ultimaker's swappable nozzle, the successful result cannot represent a successful process. In other words, the entire development process of the concept was unsuccessful if we overlook the whole picture.

Prematurely went deep into a specific concept while neglecting the possibilities of other ideas was one of the most vital mistakes we made. In fact, we disobeyed the lean methodology - being flexible. This mistake directly resulted in an increase in the time and the cost of product development. For a startup company, the expenditures of product development not only include the researching and prototyping expenses but also contain the general operating cost of running a company every single day, the salaries, the officing rentals, the administrations and so on. This is why the time and the money are equally important for startups who have limited resources.

Another big mistake we made was that we did not evaluate whether or not our own capabilities and our resources were able to manage the development of the selected concept. Perhaps the spring handle mechanism concept was a feasible idea for a big company, however, it was over challenging for us because we did not have a mechanical engineer in the team.

These two mistakes made me realized that product development in the startup environment is different from that in the traditional context in terms of both the strategic aspect and the process aspect. First of all, during the conception stage, one important point is to explore all kinds of solutions and to analyze the possibilities of each concept. The possibilities, here, not only include the conventional factors such as the manufacturing cost and difficulty, the usability and the market acceptance, more importantly, it is necessary that the team need to evaluate its capability correctly and to understand all the required resources in each step of the product development.

Secondly, being highly flexible should be implemented throughout the product development process. For example, in this swappable nozzle development project, we ordered the CNC machined prototype directly from China, this process took more than one and a half months from the technic drawing confirmation to we actually received the prototype, in which there were about ten days delivery time. In fact, we should have already realized the limitation of this decision, and at that moment, we should have discussed the feasibility of the method profoundly and stopped doing that. Not to mention that there were many vital steps where we should have turned around.

Therefore, it is important for startup companies to balance the creativity, difficulty, feasibility, cost and self-capability in product development. Sometimes, working wisely could be more meaningful than hardworking.

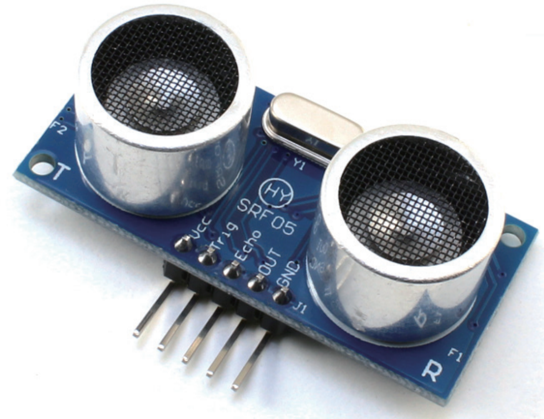
4.4 Auto bed-leveling design

Auto bed-leveling was another important hardware feature in this project, it enabled the 3D printer to achieve the full automation to a large extent because this feature converted the most painful step of using FDM 3D printer to be automatic. It is worth to mention that the auto bed-leveling feature was developed after the swappable nozzle design, therefore, I had studied the failed experiences and I adopted the improved design process. The entire development process from the conception to prototyping went very well.

4.4.1 Concept

The benchmarking enabled us to understand the working principle of auto bed-leveling. We, hence, had the research and filtration about the possible sensors that could be used for the auto bed-leveling concept. In short, auto bed-leveling is to enable the 3D printer to recognize the distance between its build plate and its nozzle; regardless of the corresponding location of these two components, the 3D printer can always actively adjust the Z-axis to ensure an even distance between the nozzle and the build plate. Therefore, the sensor must have the ability to detect the distance. We researched the proximity sensor, infrared sensor and ultrasonic distance sensor, but they all had the same drawback that the clearance between the nozzle and the sensor will confuse the precision of the auto-calibration. In addition, they all had their unique disadvantages, for example, the size proximity sensor was too big, the light interference issue for infrared sensor and the accuracy of the ultrasonic distance sensor. Therefore, we had to give up using them.

IR sensor



Ultrasonic sensor

Proximity sensor

Load sensor

FSR sensor

Figure 25 shows a range of sensors were involved in the auto bed-leveling concept development

Other than these three mentioned sensors, I accidentally found the load sensor or pressure sensor could also be used for triggering the auto bed-leveling. Speaking of that, I would like to share a story.

Figure 26 shows the digital screen of the electronic scale is displaying the weight of the object

My fascination for coffee is no less than that for design. Every morning, I use my coffee scale to precisely weight 15 grams of coffee beans and grind them into particles which size like granulated sugar, then I will brew my coffee by pouring 350 ml hot water which is 85 degrees from my Hario kettle. One day, as I was pouring water to the coffee brewer, as usual, I saw the figure on the tiny screen of my coffee scale changed from 0 to 1. That moment inspired me to think what if the build plate of the 3D printer is a scale, and when the nozzle touches this build plate, even if a slight touch that is unable to produce any deformation, there still should be a value generated. Then, if there can be three touches happening in three different places, it will form a surface, and this is the auto bed-leveling. I was convinced of this.

Therefore, we started carrying out research about different types of pressure sensors. Among all kinds of products, we chose the Force Sensing Resistor (FSR) and Load Cell as options and thereof developed the concepts. At the same time, we ordered them online.

4.4.2 Prototyping process

We started the prototyping with the FSR sensor. Because of its small size, we believe the FSR sensor could be integrated into the printer head housing. To be specific, we added a small plate underneath the heatsink of the nozzle module, at the same time, the FSR sensor was glued on top of the board in the housing which centralizes the heat sink. By doing so, once the nozzle module was inserted into the printer head housing, there would be two surfaces clamping the FSR sensor and thereby generating the pressure. Then, if the printer bed started to move upwards until it

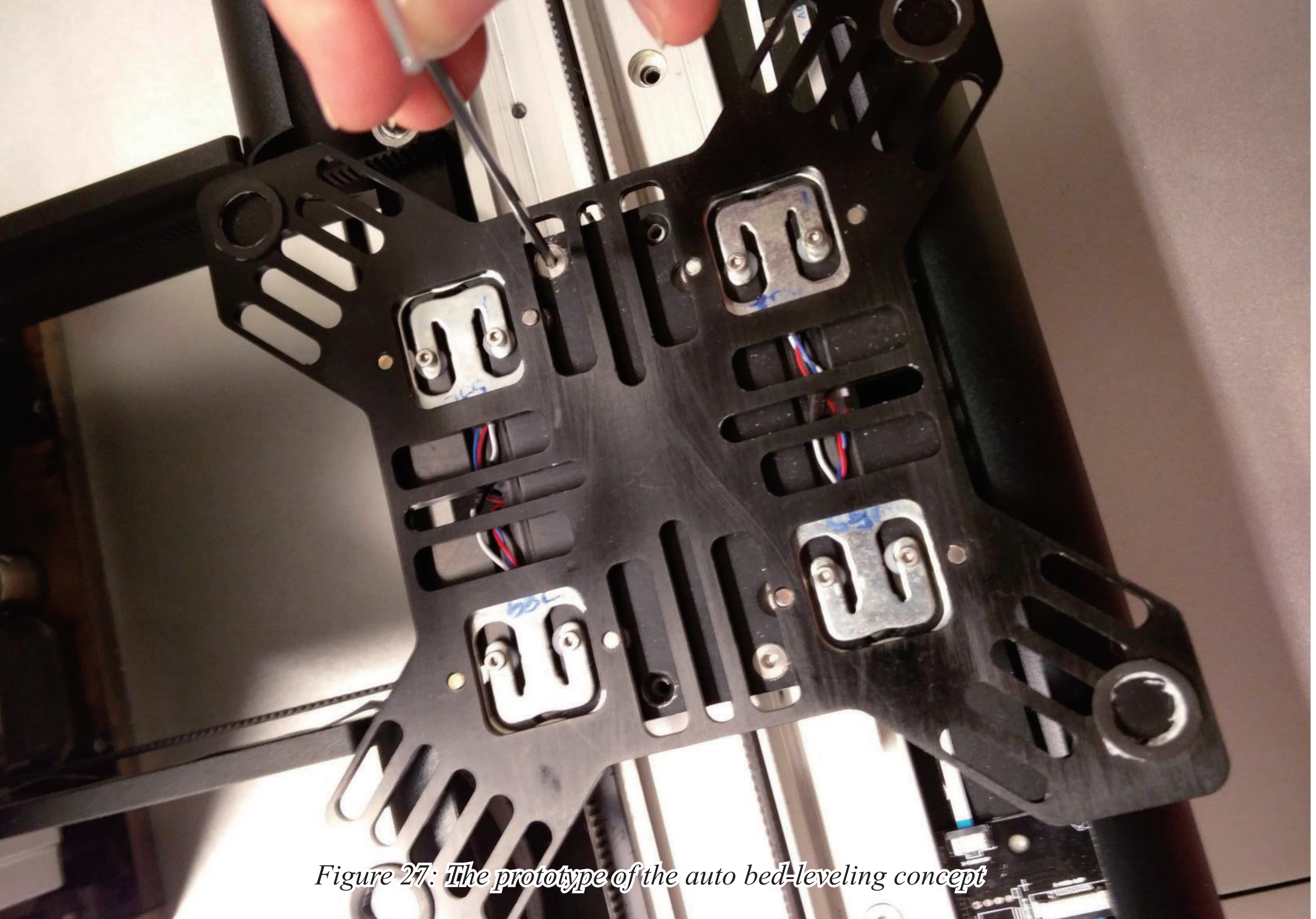


Figure 27: The prototype of the auto bed-leveling concept

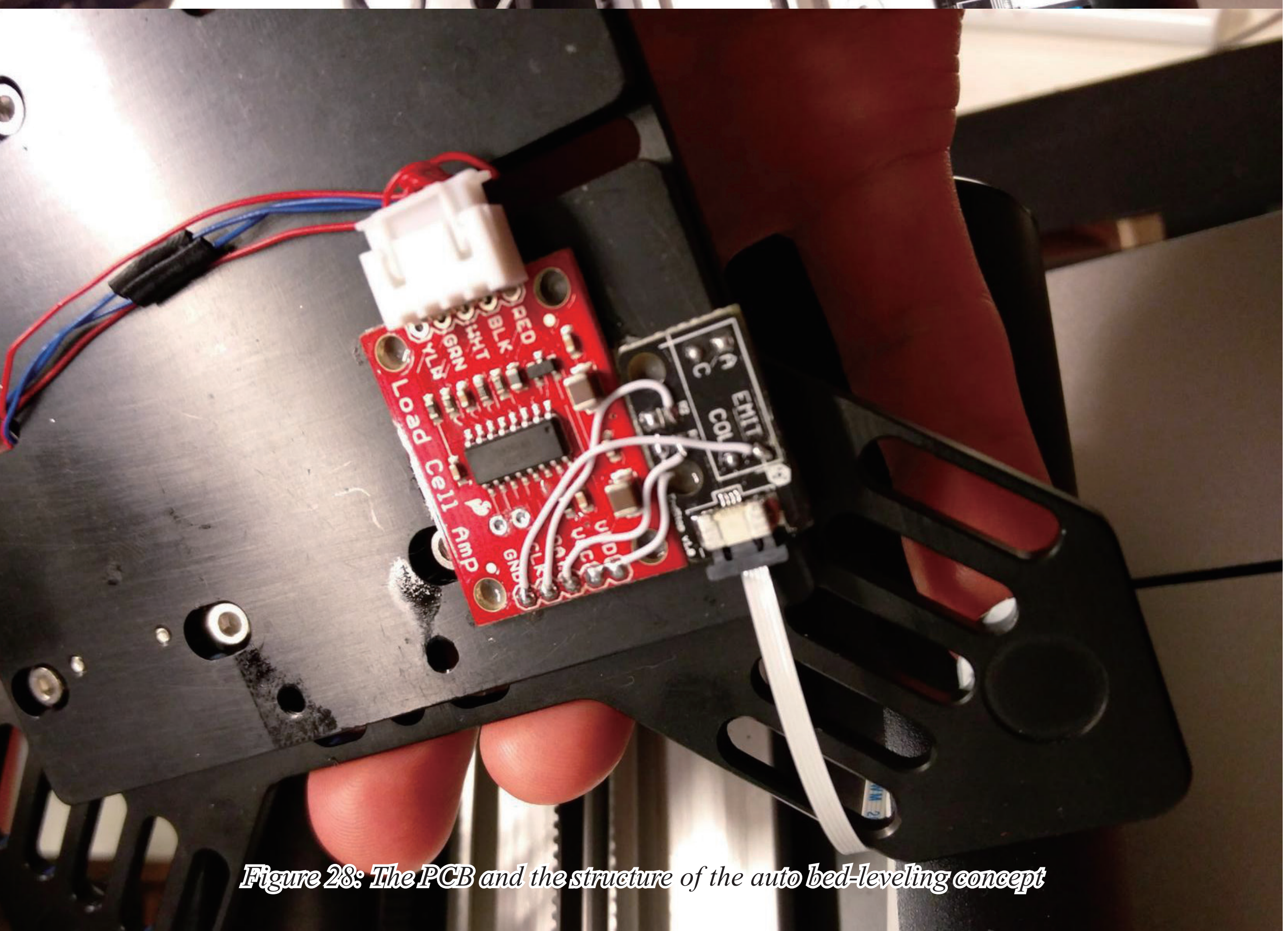


Figure 28: The PCB and the structure of the auto bed-leveling concept

touches the nozzle, the pressure of the FSR sensor would be changed because of the upwards force, this way, the leveling process would be triggered. By doing this three times on different places of the build plate, the bed leveling process would be finished.

We tested the prototype quickly. However, we noticed that after several times installing and removing the nozzle module, the FSR sensor was damaged, and changing the FSR sensor was a complex task. Therefore, given that the fragility of the FSR, we decided to stop continuing this concept temporarily and to start developing Load Cell.

The first step we did for the load sensor concept development was to put an electronic scale on the printer build plate and start to move the Z-axis of the printer upwards because we wanted to make sure the vibration of the movement would not trigger the scale. The result of the quick test proved that the idea was feasible. Then we 3D printed the fixing parts for the load sensors and installed the load cells underneath each corner of the build plate. After the hardware prototype was done, we had the test and the result was very satisfying. This concept helped the 3D printer achieve the auto bed-leveling nicely.

The auto bed leveling process took three weeks from concept design to the finishing of the prototyping. Compared to the swappable nozzle design process, it went much smoother because we kept being flexible in our mind all the time and we analyzed all the factors that could influence the development process in accordance with our abilities. The results proved that being open and being flexible is very important when doing product development in the startup environment.

Chapter 5

Customer Evaluation

During the product development finalizing stage, there were five architect firms in Helsinki that agreed with us to have a pilot programme. The pilot, on the one hand, can be considered as part of the marketing strategy, it enabled us to accumulate a certain amount of reputation and testimonial before launching the product. On the other hand, we planned to finalize the product further by this pilot, to ensure the reliability and user experience of the product.

We made 10 prototypes for the pilot programme. Among these 3D printers, five of them were used by us for the internal test and software development, the other five units were placed in piloting customer's offices. In this chapter, I will shortly introduce the process of making these 10 units. What is more, I will describe how the product was further developed based on customer feedback.

5.1 Prototyping for piloting programme

In chapter 4, I introduced the design and prototyping processes of two main hardware features of this project. In fact, along with the development of these two features, I was also designing the entire 3D printer's hardware, in which many concept sketches were drawn and evaluated, also, different levels prototypes were made according to those concepts.

As mentioned previously, we ordered the swappable nozzle prototype from China. Despite the prototype did not work as we expected, the quality of the manufacturing was satisfying, therefore, the factory who made the first prototype of the swappable nozzle became one of the suppliers, it was responsible for producing the CNC machined parts of the 10 prototypes. Other than this Factory, we also collaborated with two other factories in China, one of them was specialized in sheet metal fabrication, the other one was a professional plastic prototyping studio.

5.1.1 Reason of Prototyping in China

There were several reasons for us to make the decision that these 10 units should be produced in China, for example, the affordable price and the special surface treatment requirement. Admittedly, we understood that producing in China could bring risks to us, just like Anjoran (2017) stated that there could be many ways that importers got cheated by Chinese suppliers. However, as we all know, China is named as the "factory of the world" [METI White Paper, 2001: p.27] where produces most of the commodities for the world. It is well-known for its affordable price and quick response. The fact is that products from such as the Apple which represents the highest level of industrial design to luxury fashion accessories are all made in China, while consumers are still fascinated about them. This means "made in China" does not equate to bad quality, instead, as long as companies know the tricks of choosing the right producer in China, they can receive good quality products. One of the tips mentioned by Carlson(2015) is that it is crucial to understand the importance of cultural differences and "guanxi" (relationship) when somebody wants to produce products in China. There were two team members from China in this project, therefore, no matter from the language aspect or the cultural perspective, we all had the convincing reason to supported the decision of producing in China.

5.1.2 Prototyping and Assembling

The design was different from the traditional FDM 3D printer in terms of the visual aspect. The main body of the machine was made of 3mm aluminum sheet metal with the original color anodized. The X, Y and Z axes were located on top of the main body of the machine, and they were designed with separated structures. These three axes were packaged by matt black ABS, which gave the product a minimalist appearance. This design satisfied with the architects' requirements. Many architects mentioned in the previous user research that if they would buy a 3D printer for their office, it must look good on their desk.

The aluminum body of the 3D printer was fabricated by sheet metal bending process, the internal structures were made by both sheet metal bending and aluminum profiles. Smooth rods and bushings were used to provide mechanical movements for the X, Y and Z axes. Stepper motors

Figure 29 shows the prototypes that were produced and assembled in China

were used to drive the mechanisms. The clamping structures of the X, Y and Z axes were machined by CNC due to the accuracy requirement.

During the collaboration process with Chinese manufacturers, we used different methods to ensure the quality of the production. First of all, I had several remote meetings with them. In the meeting, I explained the purpose of each part clearly to them. After making sure that they had fully understood the requirements, we had several discussions about the production methods and the tolerance requirement. Then they started the actual production. At that time, I flew to China to visit the sheet metal bending factory. This is because the clearance of sheet metal bending was more difficult to be controlled than that of CNC, so I needed to confirm the quality of the first prototype so that they could continue.

In China, I worked with the staff in the sheet metal bending factory together to ensure the quality of the first prototype. We tried several times and eventually the outcome was satisfying. At the same time, the first set of CNC machined parts were finished as well and they were sent to the sheet metal bending factory. I directly assembled them and confirmed the quality. Then, they started producing the remaining 9 units. By the time they fully finished the parts, I had a remote inspection in Finland once again with them by using Wechat, after that, all the parts were shipped to Finland.

The entire time span of the prototyping lasted about one and a half months from the technic drawings confirmation to we received the parts. We were satisfied with the time and quality. After received the parts, we started assembling them for the user evaluation.

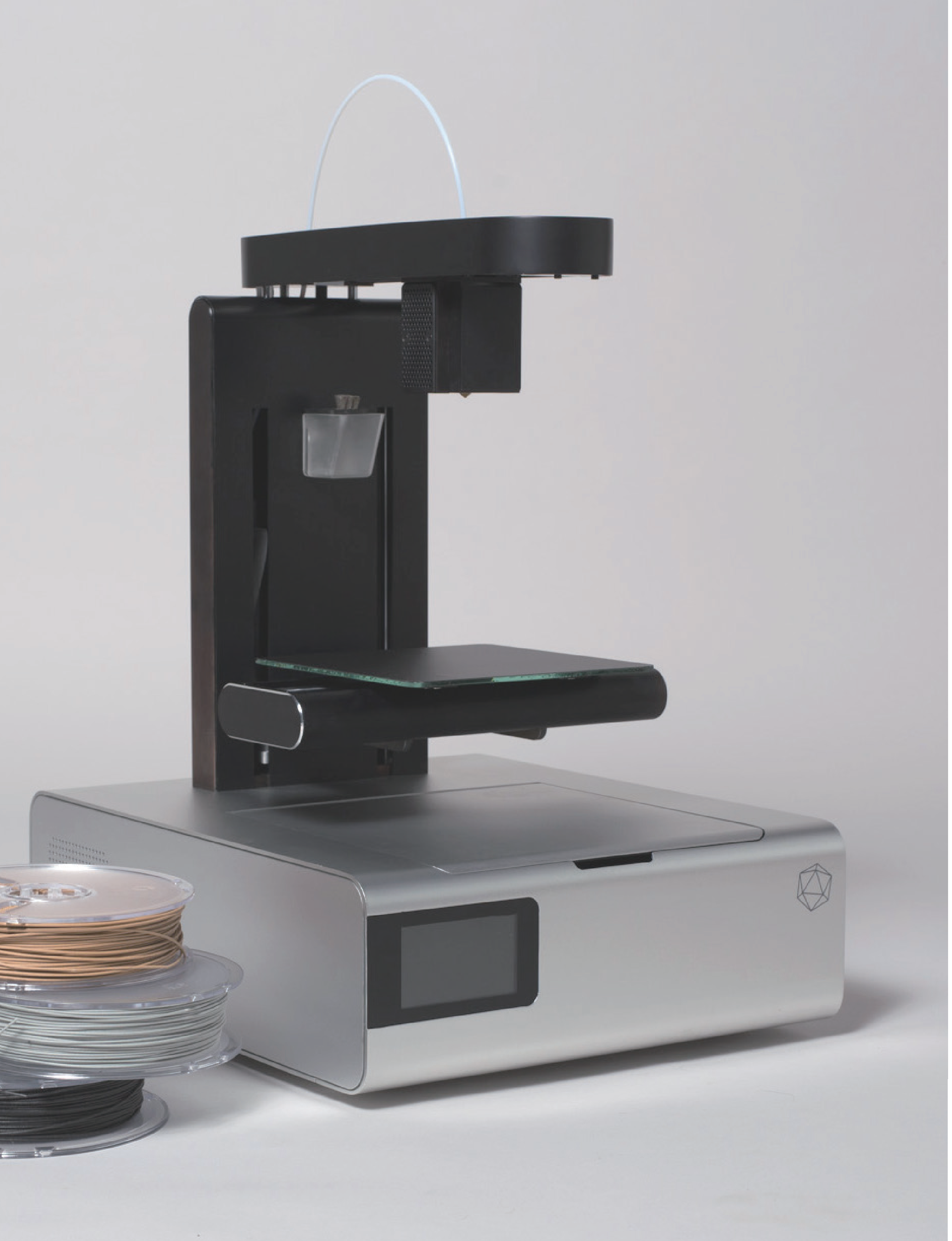


Figure 30: The final prototype

5.2 Piloting with customers

In order to further improve the prototype, we agreed with 5 architecture firms in Helsinki to carry out a pilot program. We anticipated to find some insufficient aspects existing in the prototype by this pilot and thereby to finalize the product before launching it. Just like Abu Hassan, Schattner, and Mazza (2006) mentioned, a pilot study can be defined as a 'small study' before the full-scale implementation because by which, the team is able to identify potential problems and deficiencies in advanced. Also, the software of the project was still under development stage, for example, the auto STL-generation feature. Therefore, the software was gradually updated and tested during the pilot.

5.2.1 The pilot plan

In fact, the pilot plan was already drafted when the prototypes were producing in China. We made the plan as the table listed below:

Time length of the pilot: 6 months

Customers: ALA
SERUM
LUNDEN
VERSTAS
STUDIOPUISTO

Goals: Examining the usability and the user experience of the product.

Detecting the insufficient aspects and further improve the product. Gaining more user insights.

Confirming if the product is ready for full-scale implementation.

By doing this pilot, starting to obtain reputations for marketing.

Taking piloting as the testimonials, in order to attract investment.

Enabling Architects to realize that 3D printing prototypes would benefit their design work.

Training: Before starting the piloting, each architect firm received two hours of training. The training gave instructions about how to use the 3D printer and how to optimize their 3D files in order to achieve the best print result.

Communication channels: Five Slack channels were created which enabled the clients to communicate with the team privately, letting the customers update the situation of 3D printer usage and receive supports. Each Slack channel was categorized by the technical group and the 3D print group. In the technical group, anything related to design or software matters could be posted there to obtaining supports. In the 3D print group, users could receive supports about making 3D models and could share print results with the team.

Feedback: Each week during the pilot, customers would have the meeting with us to exchange opinions about using the 3D printers.

Support: We decided that the entire team will provide support to the customers throughout the pilot period. Meaning we served them 24 hours and everyday. And the pilot customers were the top priority.

Figure 31 shows one of the architecture firms were doing the pilot

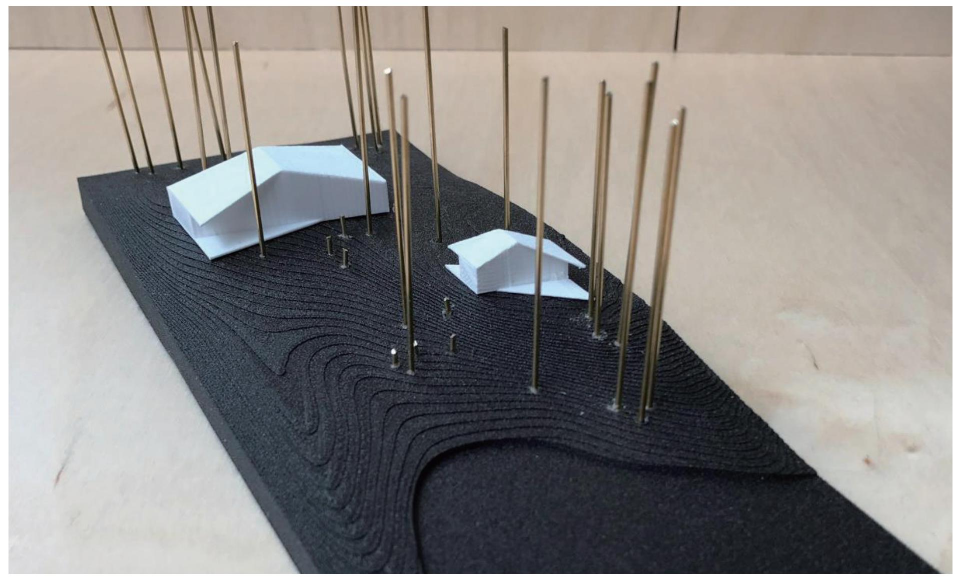


Figure 32 shows the sample that was printed during the pilot

After the pilot: After the pilot, the customers had the right to purchase the 3D printers by paying the remaining payment. If they do not like to keep owing to the product, they could return it.

5.2.2 User feedback

During the pilot, there were some problems happened when customers were using the 3D printers. We also exerted efforts to solve the problems and to provide them with the best supports. We noticed three main issues, and based on them, we generated the corresponding solutions. It is worthy to mention that one of the solutions was developed with one of the customers together.

In addition to the problems, the two key hardware new features had been tested and proved by the pilot.

The issues found during the pilot:
1.Difficult to remove the printed object from the build plate.
2.Layer shifting and noisy issue
3.Nozzle Cleaning issue

5.2.3 Improving the prototype according to user feedback.

Geckotek was used for solving the issue that difficult to remove objects from printer bed: As architects were using the 3D printers, we gradually found the 3D models they printed were different from other industries. As we all know, in most cases, architectures are located on the ground, so architects have to take landscape into consideration during the design process. Therefore, our customers often 3D printed objects which contained a huge base. In addition, they preferred to use the max print size. In other words, there was often a 200mm by 200mm by 10mm base being 3D printed during their actual usage.

However, as mentioned previously, the 3D printed object was done by melting the PLA filament to form the shape layer by layer and the first layer of the print is also done by the melted PLA sticking to the build plate. Therefore, the bigger the sticking area is, the harder for removing the printed object will be. Thus, removing the 3D printed object from the build plate had been a main issue during the pilot. Once, the customer even broke the build plate glass during the removing process.

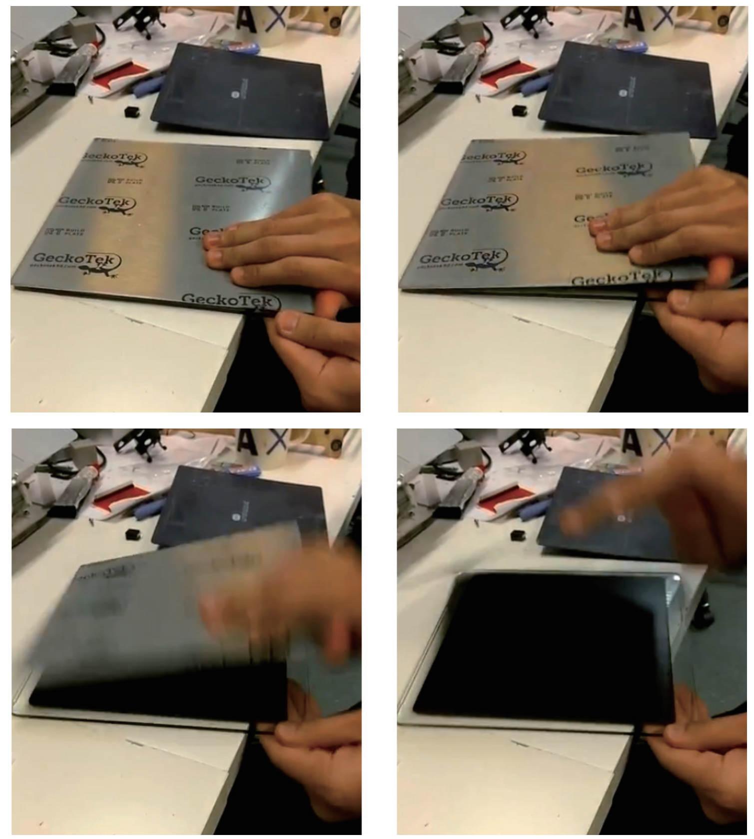


Figure 33 shows removing GeckoTek build plate

The issues mentioned were discussed internally by us, the solution was to use Geckotek (A build plate made of spring sheet metal with EZ-stik material)(GeckoTek, n.d.) to replace the glass build plate. The advantage of using Geckotek is that the bendable spring sheet metal enabled removing the printed objects easier because users could slightly bend the build plate, the printed objects would be separated.

Lubricate-free mechanisms were applied to solve the layer shifting and noisy: Another issue was that as the pilot continuing, users started to report the noise issue during the printing process. At the same time, some of the 3D printed objects appeared layer shifting problem. These problems had become more frequently day after day. Obviously, the reason for causing them was friction. The team traveled to the clients' offices to lubricate the mechanisms of the 3D printer, however, it was not a long-lasting solution, this against the idea of making a maintenance-free 3D printer.

The team, then, did the research about the better mechanism system options which could be used for 3D printer. By learning from the Youtuber Thomas Sanladerer channel, we decided to try IGUS lubrication-free linear rail system. This solution not only solved the noisy and layer shifting problems but also motivated us to start a Design for Manufacturing and Assembly (DFMA) process.

According to David Stienstra(n.d.), DFMA seeks to reduce the labour, material and overhead cost by balancing the complexity and numbers of parts. By doing it, we managed to simplify the structure and thereby reduced the cost of the manufacturing. When we were assembling the 10 units, we realized that the rod-clamping structure requires a precise CNC milling; and we had to pay extra attention when we were fastening the

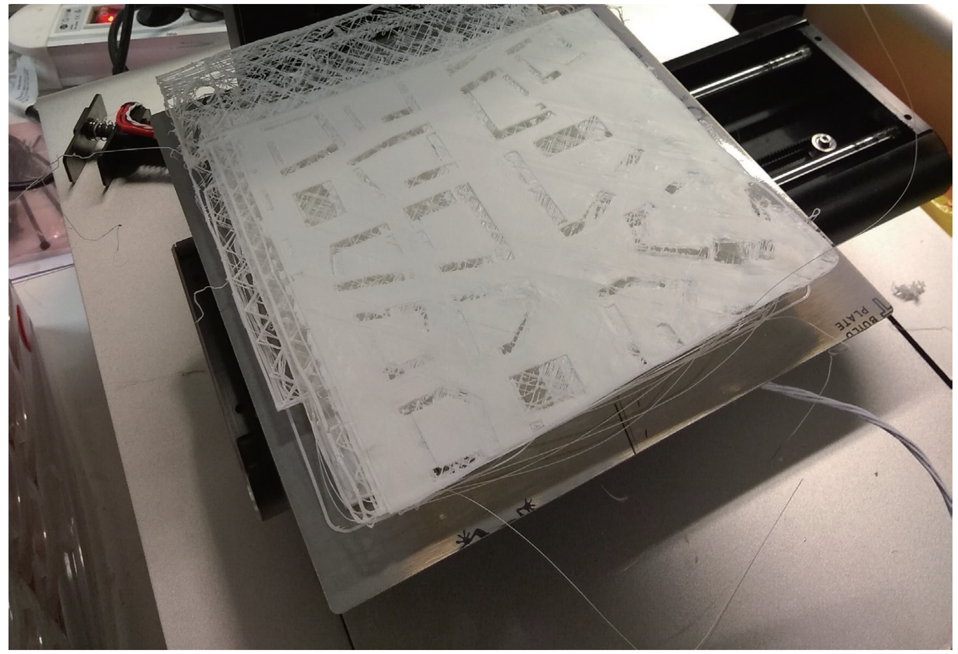


Figure 34 shows a failed print caused by lubrication problem of smooth rods

Figure 35: Prototyping the IGUS lubricate-free linear rail

smooth rods. Otherwise, the movements of the mechanism would not be smooth. Whereas the IGUS lubrication-free linear rail system could be fastened by screws, which decreased the number of parts needed on the one hand. At the same time, it provided more flexibility for the machining as there was more room to adjust during the assembling process. Last but not the least, during the DFMA and refining the mechanical design process, we reduced the weight of the product because the aluminum linear rails and its plastic guides were much lighter than the steel smooth rods and the copper bushings.

New Cleaning system designed with an architect from StudioPuisto: During the pilot program, reporting problems were not the only acquisition that we obtained. One of the architects from StudioPuisto contributed his idea to the 3D printer project. He suggested a cleaning system which could effectively remove the leftovers from the previous print, which ensured a clean nozzle and safeguarded the Auto bed-leveling.

As mentioned in Chapter 4, the load sensors would be triggered by anything that touches the build plate. This also revealed a disadvantage. To be specific, if there were leftover filaments being stuck on the nozzle and it went beyond the tip of the nozzle, the load sensor would be triggered by the leftovers which resulted in an inappropriate bed-leveling because the distance that the firmware computed was not between the nozzle and the build plate surface anymore, instead, it was between the touchpoint of leftover filaments and the build plate surface, meaning there would be a bigger gap between the bed and the nozzle during the actual printing.

This inaccurate leveling issue happened a few times in the pilot as the cleaning brush of the 3D printer got dirty thereby did not function

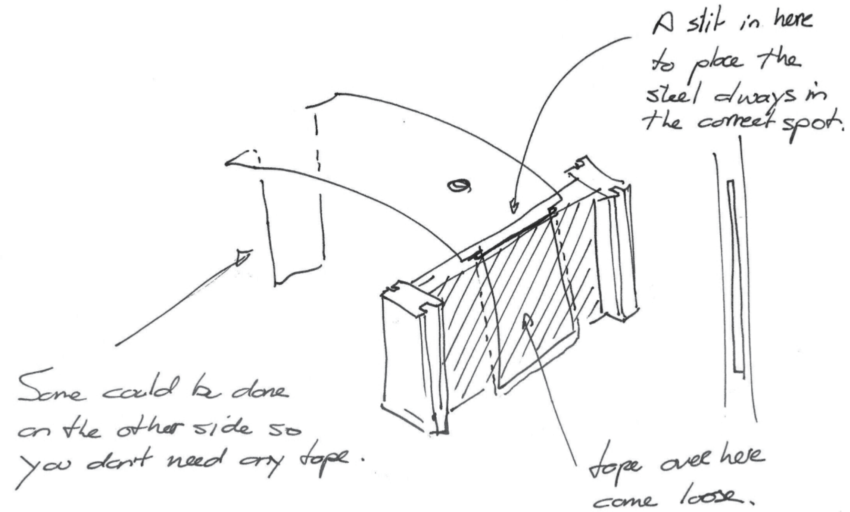


Figure 36: Sketch of the new cleaning concept provided by one of the architects during the pilot

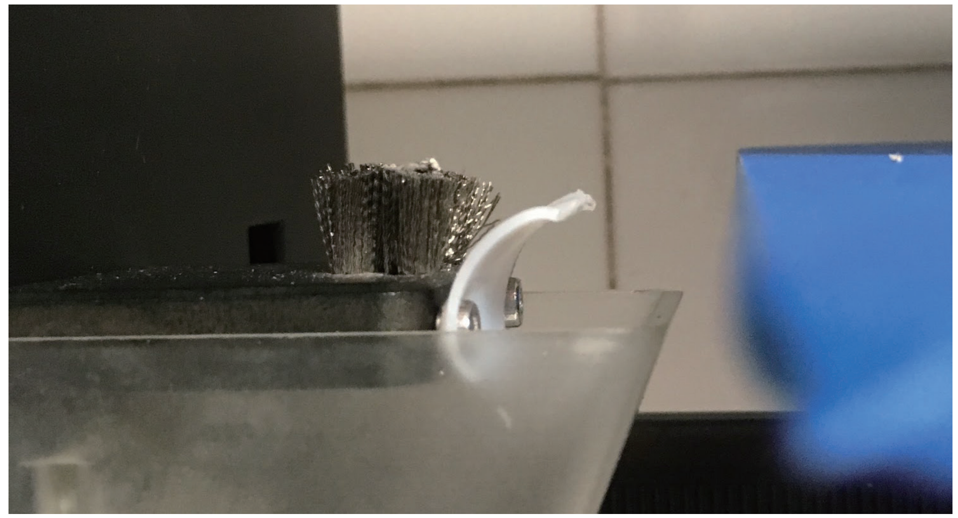


Figure 37: Prototyping the new cleaning concept which inspired by the user

properly. We were suggested by the customer that a rubber flicker would be helpful for solving the issue. He even drew a sketch to us.

This idea was quickly tested by the team and it initially worked nicely. However, some filaments were very sticky which could not be even removed by the flicker. Fortunately, By revising the cleaning procedures and adding a retraction before starting the self-cleaning step, the new cleaning system achieved a more reliable result.

5.3 End words of the pilot programme

During the half-year period pilot, the project had been finalized in terms of both hardware and software. Through closely communicating with end-users, disadvantages of the product were able to be revealed, thereby, the team could constantly work on fixing the issues to make the product to be better. Unfortunately, this project almost reached the massive manufacturing stage, but due to the funding issue, it did not. So we had to stop the project.

Despite the fact that the project did not move forward, the pilot itself had a great significance. First of all, the half-year pilot enabled most of the clients to realize that making 3D prototypes are essential, they believed that tangible prototypes bring extra value and benefits to their design work. In addition, the majority of architects in this pilot admitted that using 3D printer is much easier than they thought, they now believed that 3D printers are not designated for those specialists.

As mentioned by one of the customers Samuli Woolston, Partner at ALA:“People do not read from floor plans but from real visualizations. It is easier to communicate both with colleagues and customers the moment you are able to get your design out of a screen and into a scale model. We see a big value in scale models as we can test the best ideas, and perceive a lot of details that we can’t see on a computer screen.”

5.4 Reflection of the pilot

Looking back at the pilot, we did finish the targets that were set at the beginning. From the user evaluation and feedback, we had improved the 3D printer, enabled it to be ready for massive production. However, the strategy and the time of the pilot, perhaps, could be modified so that there could be more opportunity to get the funding or investment. Undeniable, collaborating with a few customers at the beginning of the project is very important for a startup company, but should we locate the requirements of the piloting customer as the very top priority? It was a risk because, as mentioned many times previously, a startup has limited resources, we were not able to manage the project from a strategic perspective since supporting the piloting customers’ daily tasks had already taken almost all of our time. Just like Van Teijlingen and Hundley (2002) mentioned, the pilot only represents a small number of user cases, whereas a product should be examined by a variety of opinions because investors also pay attention to the project from a holistic level. Although this was not the only reason for this project failed to receive enough investment, it indeed was one of the matters which deserved to be thought twice.

Chapter 6

Discussion & Conclusion

6.1 Discussion

“Startup” has become a popular term which is often mentioned. As we are listening to those amazing successful startup stories, a more significant number of failed cases are happening everyday. According to The Ultimate Startup Failure Rate Report 2019 (Failory, 2019), the failure rate of the startup business is about 90%, and the reason causing the failure varies. After actual experiencing this startup travel, I will be summarizing the most essential mistakes made in this project, at the same time, I will also discuss the alternative possibilities about the project based on my own understanding.

The most influential mistake of the project occurred at the beginning of the project. As mentioned previously, the project started with customer discovery and validation, it enabled the project to define the architect as the potential user group. This step, however, also limited the following user research and marketing. Besides, the other main mistake was that we failed to be flexible throughout product development. This mistake led the project to a dead-end at one point; the entire product development was, therefore, delayed.

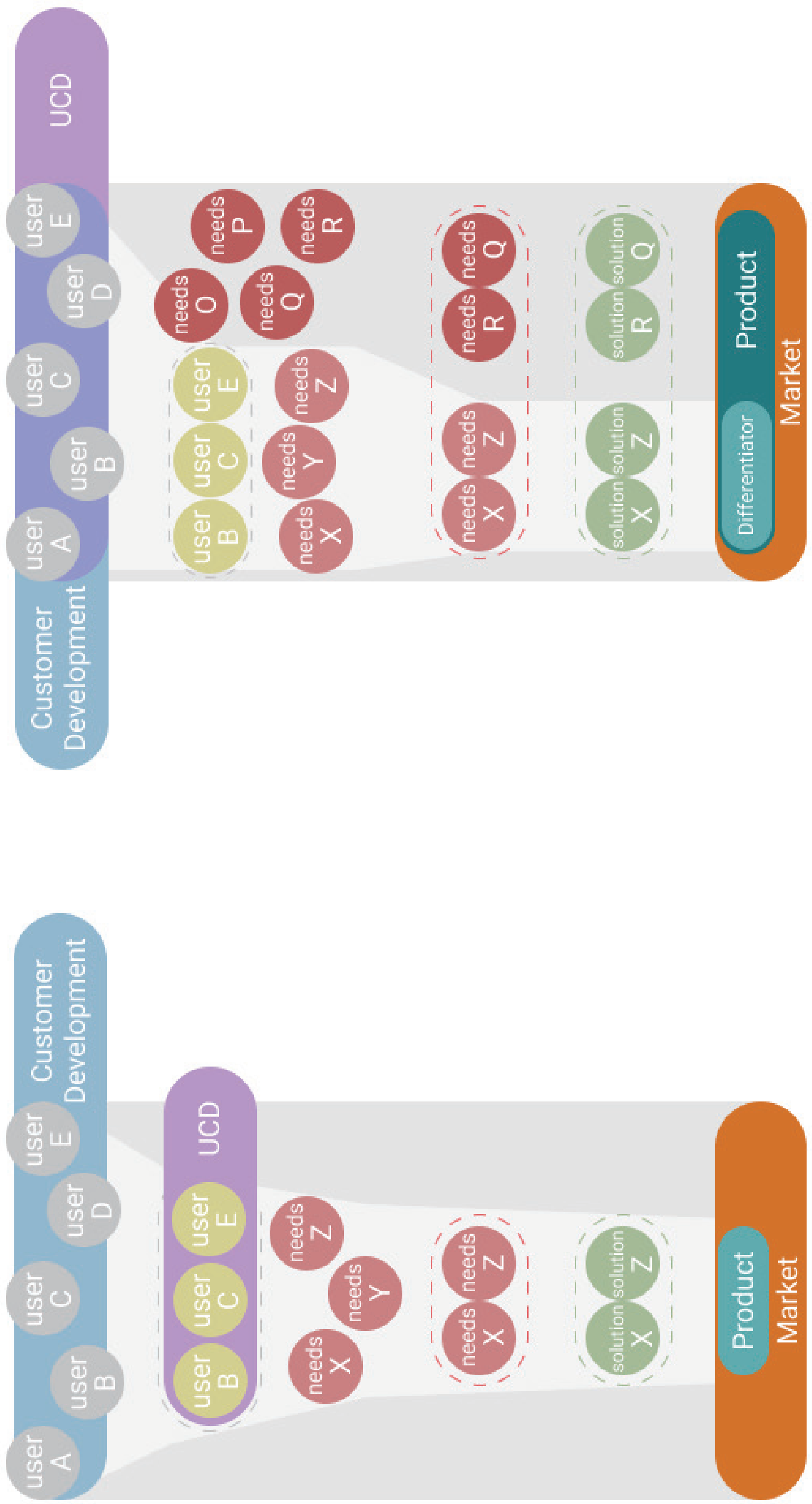


Figure 38: different product outcomes could be achieved by placing UCD in different stages

Looking at the entire process of the project, the user research and product development were carried out after the customer discovery and validation. This means that the range of the researched user group was limited by the result of customer discovery. If the essence of customer discovery and validation is to "define" who could be the customer, then, the “define” is a narrowing process. However, the UCD process requires an open-minded initial exploration, then narrowing the direction. Only by doing this can we ensure a holistic involvement in the research. This is why the user research was limited by the decision of the customer discovery and validation. Furthermore, once the user group and the market are locked prematurely, the impression and the experience that the product or the brand brings to the market will be restricted. Like Roto, Law, Vermeeren and Hoonhout(2010) mentioned that the time span of user experience is not only limited at the moment that people use the products, it actually has already been built through the promotion stage. Therefore, with the pre-solidified impression and experience, the project lost its marketing adjustability. By the time we realized that the target market needed to be expanded, the pre-built experiences had become an obstacle to the expansion.

In my perspective, the customer discovery and the user research of the project should have been carried out simultaneously. If these could be done in this way, we would still be able to conduct the conclusion that Architects will be the potential user, but they would not be the only user group to be targeted. This is because holistic user research would conclude the necessity of paying attention to the requirement other industries, thereby, it will influence business development. Then, from the marketing aspect, we would not design our tagline as “the first 3D printer for Architects”, instead, we would take architects as the most important case to market the product so that the product would have its clear defined main differentiator. From the functionality aspect, user research would also be conducted more thoroughly. By collecting a wider range of user requirements, the needs about key professional functionalities such as the dissolvable support material would not be neglected. Eventually, the product could become more accepted and more competitive, thereby, the sales and the possibility of raising fundings could be increased.

From what have been discussed above, undeniable, having a main target user group is indeed important, it benefits the marketing. However, as startup companies, being open to all the user groups should always be kept in mind. It is crucial to balance the attention paid to the target users and other users. On the other hand, user research and customer development should be carried out at the same time instead of one is more important than the other. The relationship between business and product is like a chicken and egg situation.

6.2 Conclusion

In conclusion, this thesis described the process that a startup company designed and developed its 3D printer project by using UCD method. Besides, along with the documentation of the process of the project, the author reflected the mistakes happened during the product development and considered what could be improved for developing the product in a startup context. The project consisted of three main stages, namely Customer Development and User Research, Conception and Product Design, and Prototyping and User Evaluation.

The team started with researching the 3D printer requirement of different industries, understanding their specific needs, familiarization levels and interest levels about 3D printer in general. Based on the initial research and considering the expertise of the team, the Architect industry became the target user group. Afterwards, the team carried out the user research by using UCD method. Interview with potential customers and professionals and fieldwork observation enabled the team to define the problems of using entry-level FDM 3D printers.

The user research led to the key features of the 3D printer such as the swappable nozzle, auto bed-leveling and automatic STL file converting. These features were developed in the second stage which solved the challenges of using 3D printers. The thesis mainly described the hardware features. Also, in this stage, the team conducted the workshop with the support of two other designers. The benchmark also was carried out.

During the third stage, the team made the prototypes and had the pilot with five architecture firms in Helsinki. The pilot lasted for 6 months which brought huge value to the project. The product was finalized based on the user feedback and it was ready to be manufactured.

In addition to the explanation of the product development process, the thesis has a reflection at each stage, and at the end of the thesis, the author summarized and analyzed the mistakes, by doing that, the author attempted to figure out the way of avoiding those mistakes so that the project could have alternative results, or at least, it would not end with funding and sale issues.

The following contents will answer the research questions.

In the startup context, how User-Centered Design can be used to make the entry-level FDM 3D printer become a useful tool to improve the working efficiency of Architect?

Interacting with users throughout the entire product development process: The interaction with the users had always been playing a vital role in each stage of the project regardless of the business development or product development. Although there were mistakes, the interview in the first stage provided constructive value to the team because it enabled the team to understand the users' pain points and the requirements in terms of using 3D printers. This resulted in the development of the key features which improved the user experience and made the 3D printer more valuable for architects. Furthermore, the frequent interaction with the users during the pilot program enabled the team to notice the deficiency of the prototype, by collecting user feedback and collaborate with the customers, the project was technically ready for its production stage. Therefore, understanding the requirement of user by communicating with them throughout the product development process should be one of the factors that how UCD can make an effect.

Understanding the requirements of both the general users and the target users: As has been discussed in the second chapter 2, the key of the UCD is to understand the requirement of the user, then generating solutions according to user requirements. Therefore, defining the most valuable user requirements is essential. The project conducted a good user research for its targeting user group and developed the corresponding features which satisfied architects' requirements. However, if the researched user groups could be wider involved, a more holistic user requirement would be obtained and, thereof, the product would be more competitive in terms of both functionality aspect and marketing aspect. In other words, the professional function requirements were not mentioned during the interview with architects, but it does not mean they do not need these features, with those features, the product should be more valuable for architects.

How UCD should be located in startup business?

Although the project failed, the role that UCD can play in startup business development can be clarified. It is worth to mention that this will be mainly about the product-oriented startup. To be specific, in the startup business, User research and customer development are correlated; they are equally important. If UCD is conducted under the frame structured by the customer development, the exploration about user requirement and the product concept will not be completed. Therefore, it is important that startup companies should place the user research and customer development on the same level. The research targets not only should cover potential customers, but other users' needs should also be taken into consideration. This ensures the product to be unique while professional. Hence, UCD should not be limited by the frame defined by customer development. An inclusive UCD benefits the startup business development, it enables the startup to be more flexible and helps the startup to deal with the rapid changes.

References

Anjoran, R. (2017). How To Cooperate With Your Chinese Supplier, Part 15: The 7 Major Risks You Run With Your China Manufacturers. Retrieved February 21th 2019 from https://qualityinspection.org/major-risks-china-factory/

Attaran, M. (2017). The rise of 3-D printing:The advantages of additive manufacturing over traditional manufacturing. https://doi.org/10.1016/j.bushor.2017.05.011

Baldwin, C. Y. & Clark, K. B. (2004). Modularity in the Design of Complex Engineering Systems. Retrieved March 18th 2019 from http://www.people.hbs.edu/cbaldwin/dr2/baldwinclarkces.pdf

Bhutta, K. S. & Huq, F. (1999). Benchmarking – best practices: an integrated approach. P.255. DOI: 10.1108/14635779910289261
APQC. (1996). Emerging Best Practices in Knowledge Management.

Blank, S & Dorf, B. (2012). The Startup Owner's Manual: The Step-by-Step Guide for Building a Great Company

Bogner,A. Littig, B. & Menz, W. (2009). Interviewing_Experts. Introduction: Expert Interviews – An Introduction to a New Methodological Debate. p.2-12. Retrieved April 16th 2019 from https://www.researchgate.net/publication/284419200_Interviewing_Experts

Carlson, B. (2015 September 23). Why big American businesses fail in China. Retrieved February 22th 2019 from https://www.nbcnews.com/news/china/why-big-american-businesses-fail-china-flna4B11231213

Chapple, A. (1999) Issues in research. The use of telephone interviewing for qualitative research. Nurse Researcher, 6, 85-93.

Dorussen, H.; Lenz, H. & Blavoukos, S. (2005). Assessing the Reliability and Validity of Expert Interviews. European Union Politics, 6(3), P. 315-337

Elmuti, D. & Kathawala, Y. (1997). An overview of benchmarking process: a tool for continuous improvement and competitive advantage. Retrieved March 14th 2019 from https://pdfs.semanticscholar.org/8748/092dcb7f88ab1e1f09d7826f8c07402918ce.pdf

Evered, R. and R. Louis (1981). Alternative Perspectives in the Organizational Sciences: 'Inquiry from the Inside' and 'Inquiry from the Outside'. Academy of Management Review, 6 (3): 385- 395 https://ualr.edu/interdisciplinary/files/2010/03/Qualitative_Research.pdf page 4

Failory. (2019). The Ultimate Startup Failure Rate Report. Retrieved June 5th 2019 from https://www.failory.com/blog/startup-failure-rate

Fordyce, A. & Me3D. (n.d.). Me3D Pty. Ltd. Help Centre. Common Problems. Nozzle Height. Retrieved March 5th 2019 from https://support.me3d.com.au/hc/en-au/articles/333757004395-Nozzle-Height
Garbett, R. & McCormack, B. (2001). The experience of practice development: an exploratory telephone interview study. Journal of Clinical Nursing,10(1):94-102.

Geckotek. (n.d.). https://www.geckotek.co/

Griffith, E. (2014, September 24). Why startups fail, according to their founders. Retrieved from https://fortune.com/2014/09/25/why-startups-fail-according-to-their-founders/

Hassan, Z. A., Schattner, P. & Mazza, D. (2006). Doing A Pilot Study: Why Is It Essential? Available from: https://www.researchgate.net/publication/26498016_Doing_A_Pilot_Study_Why_Is_It_Essential

IDEO Design Kit. (2015). Human-centered design. Retrieved April 8th 2019 from http://www.designkit.org/human-centered-design

IDEO Design Kit. (2015). Interview. Retrieved April 15th 2019 from http://www.designkit.org/methods/2

Jones, R.; Haufe, P.; Sells, E.; Iravani, P.; Olliver, V.; Palmer, C.; Bowyer, A. (2011). Reprap– the replicating rapid prototyper. Robotica 29 (1): 177–191. doi:10.1017/s026357471000069x.

Kearney, A. T. (2017). White Paper. Technology and Innovation for the Future of Production: Accelerating Value Creation. Retrieved January 14th 2019 from http://www3.weforum.org/docs/WEF_White_Paper_Technology_Innovation_Future_of_Production_2017.pdf

Keinonen, T. (2010). Protect and Appreciate – Notes on the Justification of User Centred Design. International Journal of Design. P. 17-27

Marcincinova, L. N. & Kuric, I. (2012) Basic and Advanced Materials for Fused Deposition Modeling Rapid Prototyping Technology. P.24-25. Retrieved February 5th 2019 from https://pdfs.semanticscholar.org/1ecc/fa155a85a8d399c875984a5e4c2d004a547c.pdf

Markham, A. N. (2010). Internet Research. Retrieved March 2nd 2019 from https://annettemarkham.com/writing/silverman2011draft.pdf

MatterHackers (n.d.). Retrieved February 6th 2019 from https://www.matterhackers.com/store/c/Nozzles

McCue, T. (2018). Wohlers Report 2018: 3D Printer Industry Tops $7 Billion. Retrieved January 15th 2019 from https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/

METI, (2002). METI White Paper Year 2001. Retrieved February 21th 2019 from http://www.meti.go.jp/english/report/index.html

Norman, D.A. (2005). Human-centered design considered harmful. DOI: 10.1145/1070960.1070976

Norman, D. A. (2013). The design of everyday things. New York, NY: Basic Books.

Novick, G. (2008). Is There a Bias Against Telephone Interviews In Qualitative Research? Retrieved April 7th 2019 from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3238794/

O'Dell, C. & Grayson, C. J. (1998). If Only We Knew What We Know: Identification and Transfer of Internal Best Practices. Retrieved March 13th 2019 from https://doi.org/10.2307/41165948

Ospina, S. (2004). Qualitative Research. Retrieved Febrary 25th 2019 from https://ualr.edu/interdisciplinary/files/2010/03/Qualitative_Research.pdf

Pallasmaa, J. (2009). The Thinking Hand: Existential and Embodied Wisdom in Architecture

Piercet. (2018, January 9). Retrieved March 10th 2019 from https://forum.lulzbot.com/viewtopic.php?t=7079

Raquez, J.-M.; Habibi, Y.; Murariu, M.; Dubois, P. (2013). Polylactide (PLA)-based nanocomposites. Prog. Polym. Sci. 2013, 38, 1504–1542. DOI: 10.1016/j.progpolymsci.2013.05.014

Richards, L. & Chron.com. (n.d.). The Importance of Product Positioning to the Marketing Plan. Retrieved March 7th 2019 from
https://smallbusiness.chron.com/importance-product-positioning-marketing-plan-24275.html

Richter, A. & MatterHackers, (2017, April 6). How To Unclog a 3D Printer Nozzle. Retrieved March 2nd 2019 from https://www.matterhackers.com/news/how-to-unclog-a-3d-printer-nozzle

Ries, E. (2011). The Lean Startup Methodology. Retrieved April 10th 2019 from https://exclusivemotivation.com//wp-content/uploads/2017/04/The-Lean-Startup-.pdf

Rohrer, C. (2014). When to Use Which User-Experience Research Methods. Retrieved January 17th 2019 from https://www.nngroup.com/articles/which-ux-research-methods/

Roto, V. & Law, E. & Vermeeren, A. & Hoonhout, J. (2010). Demarcating User eXperience. Dagstuhl Seminar Abstracts Collection, Sections 2.1-2.5.

Sanders, E. B.-N. (2002). From User-Centered to Participatory Design Approaches. In Design and the Social Sciences (Vols. 1–0, pp. 1–8). Retrieved April 8th 2019 from http://maketools.com/articles-papers/FromUsercenteredtoParticipatory_Sanders_%2002.pdf

Sculpteo (n.d.). Extruder: essential part of a 3D Printer. Retrieved February 5th 2019 from https://www.sculpteo.com/en/glossary/extruder-definition/

Simplify 3D. (n.d.). Beginner’s Guide to Auto Bed Leveling in Simplify3D. Retrieved March 10th 2019 from https://www.simplify3d.com/support/articles/beginners-guide-to-auto-bed-leveling/

Stienstra, D. (n.d.). Introduction to Design for (Cost Effective) Assembly and Manufacturing. Retrieved April 5th 2019 from http://me.gatech.edu/files/capstone/L071ME4182DFA

Stiftung, H. B. (n.d.). How to Conduct User Interviews. Retrieved April 8th 2019 from https://www.interaction-design.org/literature/article/how-to-conduct-user-interviews

Stratasys. (n.d.). What is FDM Technology. Retrieved February 4th 2019 from https://www.stratasys.com/fdm-technology

Sturges, J. E., & Hanrahan, K. J. (2004). Comparing telephone and face-to-face qualitative interviewing: A research note. Qualitative Research, 4(1), 107-118.
http://dx.doi.org/10.1177/1468794104041110

Sweet, L. (2002). Telephone interviewing: is it compatible with interpretive phenomenological research? Contemporary nurse: a journal for the Australian nursing profession, 12(1):58-63. DOI: 10.5172/conu.12.1.58

Tandon, S. & Quartz|INDIA. (2018, May 28). IKEA’s got a plan to help Indians assemble its DIY furniture. Retrieved March 8th 2019 from https://qz.com/india/1289008/ikeas-got-a-plan-to-help-indians-assemble-its-diy-furniture/

Tausig, J. E., & Freeman, E. W. (1988). The next best thing to being there: Conducting the clinical research interview by telephone., American Journal of Orthopsychiatry, 58(3), 418-427.
http://dx.doi.org/10.1111/j.1939-0025.1988.tb01602.x

Tyson, E. & Rigid.ink, (n.d.). Clogged Extruder Nozzle? – What Causes It, How to Avoid It, and How to Fix It. Retrieved March 5th 2019 from
https://rigid.ink/blogs/news/clogged-extruder-nozzle-what-causes-it-how-to-avoid-it-and-how-to-fix-it

Van Teijlingen, E. R. & Hundley, V. (2002). Nursing standard: official newspaper of the Royal College of Nursing 16(40):33-6. The Importance of Pilot Studies. DOI: 10.7748/ns2002.06.16.40.33.c3214

Winnan, D. C. (2013). 3D Printers - The Next Technology Gold rush 3D printing technology.

Wohlers, T & Gornet, T. (2014). History of additive manufacturing by Terry wohlers and Tim Gornet. Retrieved January 14th 2019 from http://www.wohlersassociates.com/history2014.pdf

Zhang, j & Jung, Y. G. (2018). Additive Manufacturing: Materials, Processes, Quantifications and Applications

List of Figures

APPENDIX

Customer Discovery questionnaire

1. Have you used 3D printers?

2. How much do you know 3D printer?

3. What did you / are you using 3D printers for?

4. What other methods do you use for making a tangible prototype?

5. What advantages and disadvantages does 3D printer have compared to the mentioned methods?

6. Can you guide me through a typical design work you have done in which you used 3D printer or other prototyping methods?

7. If you have 3 major problems you want to solve your 3D printer, what are they, and why are they so important?

8. Are these problems limited to you? Or do other users also identify with these?

9. If you could have a magic wand and change anything in the printer, what would it be? (What would you like us to improve in 3D printing?)

10. What are the key features that you need for 3D printers, and why?

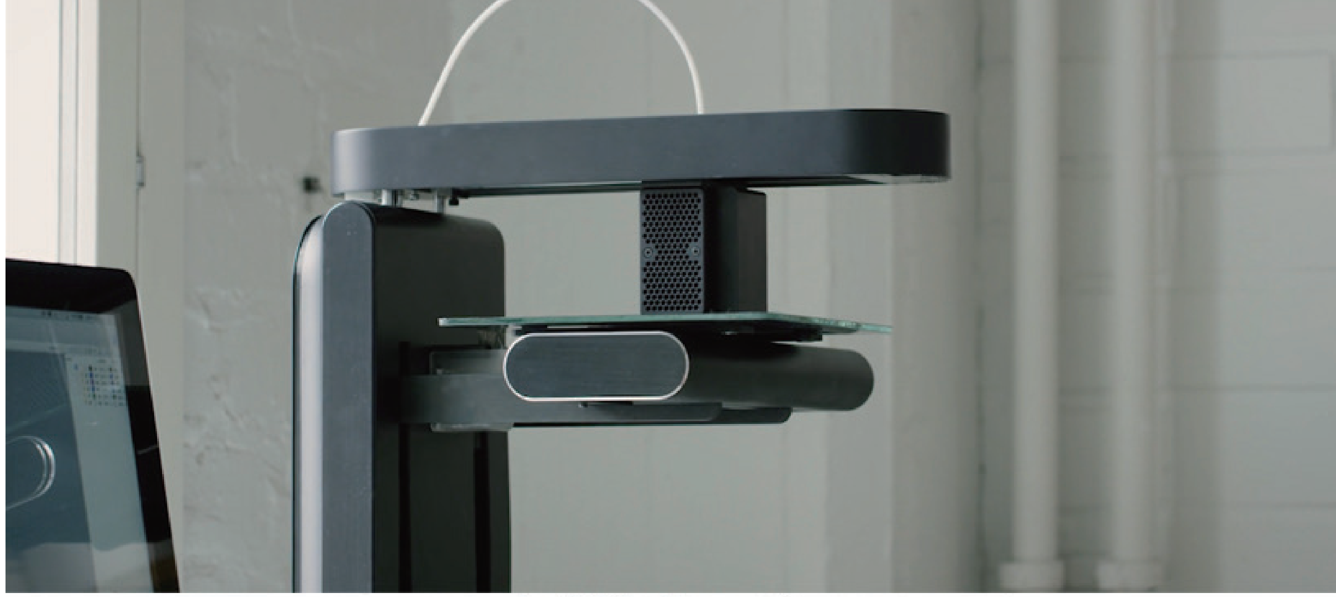
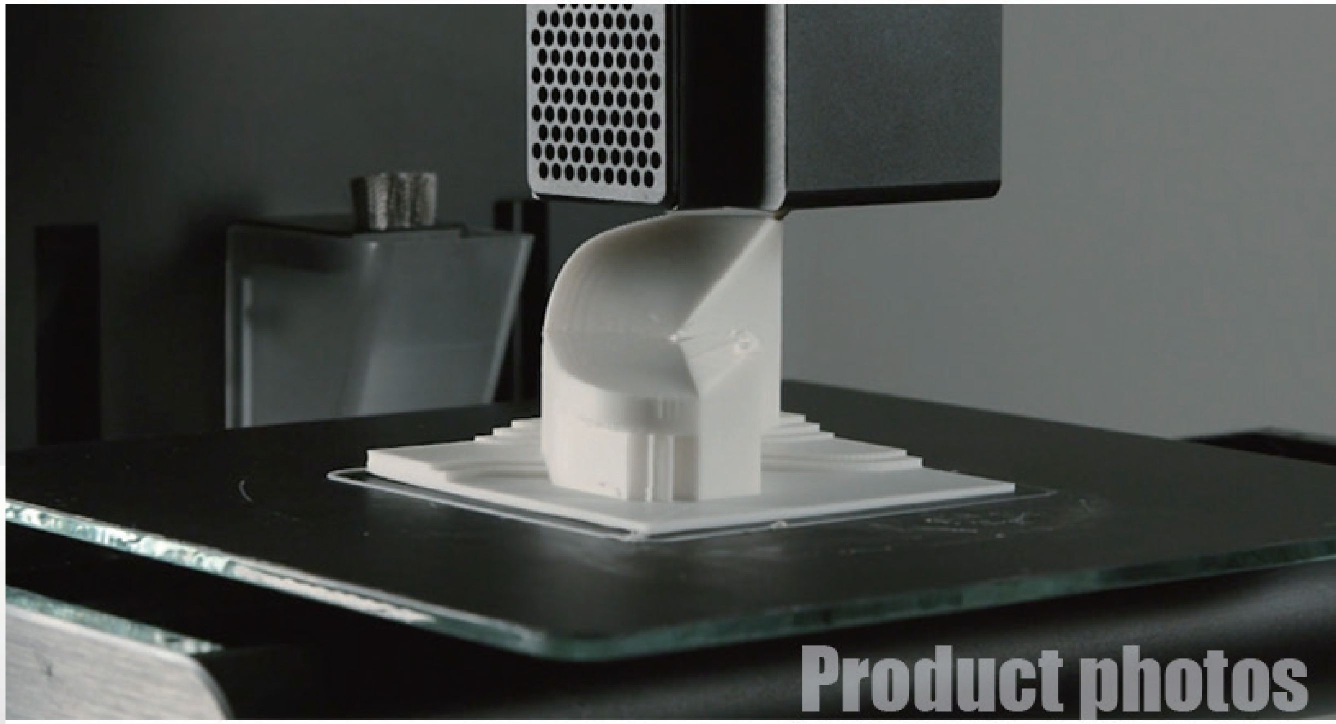
11. If you would have a printer that is fully automated (hardware & software automation) so that it requires no calibration, cleaning, and no parameter configuration, would it solve the problem mentioned earlier?

12. How do you evaluate new products? (price? performance? features?)

13. What do you think would be the barriers for stopping you buying a 3D printer?

14. What are the online sources that you read to influence your purchasing decision?





Product photos


Aalto University
School of Arts, Design
and Architecture

Huiyang Yu
Aalto University
Department of Design
Collaborative and Industrial Design
Master Thesis
2019